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CONSTITUTION AND POLYMORPHISM OF THE PYROAURITE AND SJÖGRENITE GROUPS

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ABSTRACT

The carbonate-hydroxides pyroaurite, stichtite and hydrotalcite are shown by *x*-ray study to be isostructural. The dimorphism suggested by Aminoff and Broomé in 1930 for pyroaurite is definitely proven, and is shown to extend to stichtite and hydrotalcite. Rhombohedral and hexagonal groups are recognized both of which conform to the formula $Mg_6R_2(OH)_{16}CO_3 \cdot 4H_2O$, where R^3 = Fe,Cr or Al. Data for the six species involved (three being here described as new) follow:

RHOMBOHEDRAL OR PYROAURITE GROUP

	Cell Contents (Hexagonal unit)	a_0	c_0	ω	ϵ	Proven Localities
Pyroaurite	$3(Mg_6Fe_2(OH)_{16}CO_3 \cdot 4H_2O)$	6.19	46.54	1.564	1.543	8
Stichtite	$3(Mg_6Cr_2(OH)_{16}CO_3 \cdot 4H_2O)$	6.18	46.38	1.545	1.518	3
Hydrotalcite	$3(Mg_6Al_2(OH)_{16}CO_3 \cdot 4H_2O)$	6.13	46.15	1.511	1.495	4

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Hexagonal or Sjögrenite Group (New)

Sjögrenite	$Mg_6Fe_2(OH)_{16}CO_3 \cdot 4H_2O$	6.20	15.57	1.573	1.550	1
Barbertonite	$Mg_6Cr_2(OH)_{16}CO_3 \cdot 4H_2O$	6.17	15.52	1.557	1.529	3
Manasseite	$Mg_6Al_2(OH)_{16}CO_3 \cdot 4H_2O$	6.12	15.34	1.524	1.510	3

The observed structural cells derived from single-crystal and powder *x*-ray pictures have one-half a_0 and c_0 for the rhombohedral series and one-half a_0 for the hexagonal series as compared with the values cited. The dimensions here given are required for rational cell contents. Dimensionally, $c_{0(\text{rh.})}:c_{0(\text{hex.})}=3:1$ and the halved value of a_0 (*ca.* 3.1) for both series is nearly identical with $a_0=3.12$ of brucite.

The hexagonal and rhombohedral polymorphs very commonly occur intimately admixed, and in part are mutually oriented with rhombohedral $\{0001\}$ $[10\bar{1}0]$ parallel hexagonal $\{0001\}$ $[1010]$. The minerals are lamellar on $\{0001\}$, often with partially or completely random stacking of microcrystals about $[0001]$.

Brugnatellite, $Mg_6Fe(OH)_{13}CO_3 \cdot 4H_2O$, is distinct from the minerals at hand, and the identity of houghite with hydrotalcite is confirmed. New localities for pyroaurite include Val Malenco and Val Ramazzo, Italy, and the first occurrence in the United States, at Blue Mont, Maryland.

Introduction

The constitution and inter-relations of pyroaurite, stichtite, hydrotalcite and brugnatellite have long been matters of much confusion and uncertainty. The principal factors contributing to this have been the lack of adequate crystallographical data, and the complex and somewhat unusual composition of the several species coupled with the generally unsatisfactory nature of the available chemical analyses. A further complicating factor has been the lack of correlation between the many published contributions to the subject. In particular, the *x*-ray study of pyroaurite by Aminoff and Broomé in 1930, with its indication of polymorphism, has been overlooked. The work of Manasse in 1915 which established the constitutional role of CO_2 in hydrotalcite and pyroaurite also has gone unnoticed.

In the present study it was found by *x*-ray and optical methods that almost all specimens of hydrotalcite, stichtite and pyroaurite, regardless of locality, are not homogeneous, but are intimate mixtures of hexagonal and rhombohedral substances of very similar physical and identical chemical properties. The earlier work will be reviewed in detail before the descriptive part of the study is presented.

Acknowledgments

The writer wishes to express his thanks to Dr. H. V. Ellsworth of the Geological Survey of Canada, for a gift of pyroaurite from Rutherglen, Ontario, recently analyzed by him, and to Dr. E. Poitevin also of the

Geological Survey of Canada, for a gift of stichtite from Black Lake, Quebec. Grateful acknowledgment likewise is made to Dr. W. F. Foshag, U. S. National Museum, for a loan of a specimen of hydrotalcite from Kongsberg, Sweden, analyzed by him in 1920, and for other specimens of hydrotalcite and brugnatellite. Other study material included stichtite from Barberton, Transvaal, presented to the Harvard collection by A. L. Hall and presumably part of the material analyzed by him in 1922, and a large suite of specimens of pyroaurite from Långban, Sweden, mostly from the collection of G. Flink. Additional study material is described on the following pages. The writer also wishes to express his appreciation to Professor Harry Berman, Harvard University, for his interest and aid in the investigation.

Rhombohedral or Pyroaurite Group

Pyroaurite

Historical. Pyroaurite was originally described and analyzed from Långban, Sweden, by Igelström (1865). Additional analyses were later contributed by Mauzelius (in Flink, 1910), Johansson (in Aminoff and Broomé, 1930) and Manasse (1915). Subsequently a pyroaurite-like mineral was found at Haaf-Grunay, Scotland, by Heddle (1878), who proposed the new name igelstromite, and the mineral was later said (Heddle, 1910) to occur at Hagdale and Nikka Vord, Unst. The analyses of the Haaf-Grunay material are relatively low in CO_2, and Foshag (1920) has suggested that the material was probably a mixture of brucite, hydromagnesite and limonite. This interpretation seems improbable, since Heddle states that the ignited mineral is strongly magnetic; ignited pyroaurite is highly magnetic due to the conversion of the Fe^3 to γ-Fe_2O_3 (maghemite).[1] In 1894 a new occurrence of pyroaurite was discovered at Nordmark, Sweden, by Sjögren and was analyzed by Mauzelius. This material is notable for the large content of MnO (4.5 per cent) and for the apparent absence of CO_2. The CO_2 was not sought in the analysis and may have been included in the H_2O as determined by loss on ignition. More recently, analyses have been reported by Kurnakov and Černych (1928) of material from Bashenowo in the Urals, and by Ellsworth (1939) of exceptionally pure material from Rutherglen, Ontario. The Bashenowo material contains a notable amount of Al, apparently in substitution for Fe, but possibly due to admixture. Pyroaurite also has been reported from Kraubat, Styria, and from two localities in southern Serbia by Meixner (1937, 1938) but chemical analyses are lacking.

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[1] The nature and orientation of the ignition products of pyroaurite will be described jointly with H. V. Ellsworth in a forthcoming paper.

The formula $3Mg(OH)_2 \cdot Fe(OH)_3 \cdot 3H_2O$ originally derived by Igelström was accepted by Sjögren (1894) and by Aminoff and Broomé (1930), and the considerable and rather even tenor of CO_2 in the analyses was ascribed to alteration. The analyses by Heddle (1878) of the pyroaurite-like mineral from Haaf-Grunay are close to the formula given above. Manasse, in 1915, re-examined the composition of the mineral in the light of a dehydration study and three new analyses, and concluded that the CO_2 was constitutional. The formula derived by Manasse is

$$Mg_6Fe_2(OH)_{16}CO_3 \cdot 4H_2O \cdot$$

Later, Foshag (1920) independently reached the conclusion that the formula given above represented the composition of the species. Ellsworth (1939) on the basis of new analyses and a dehydration study of unquestionably fresh material from Ontario, also concludes that this formula is correct, but indicates that the content of water of crystallization probably is closer to $5H_2O$ than $4H_2O$. The analyses of Ellsworth (1939), Johansson (in Aminoff and Broomé, 1930) and Manasse (1915) are cited in columns 1, 2 and 3, in Table 1.

Table 1. Chemical Analyses and Cell Contents of Members of the Pyroaurite and Sjögrenite Groups

	1	2	3	4	5	6	7	8
MgO	35.84	35.44	35.60	37.72	39.72	39.84	36.76	39.38
FeO		0.10			0.28			
MnO	0.01	0.28						
Fe_2O_3	23.37	23.19	23.73	4.18	1.89	0.90	0.20	0.21
Cr_2O_3				14.51				
Al_2O_3		0.11		2.30	15.32	15.16	19.65	16.59
CO_2	7.30	7.01	6.49	7.15	7.60	7.26	6.98	7.48
H_2O	33.66	33.62	33.12	34.14	35.46	36.83	36.13	36.34
Rem.		0.41	0.67		0.44	0.14	0.35	
Total	100.18	100.16	99.61	100.00	100.71	100.13	100.07	100.00

Cell Contents of the Rhombohedral Polymorphs

	1	2	3	4	5	6	7	8	Theory
Mg	17.8	17.6	17.7	18.3	17.9	18.0			18
Fe	5.8	5.8	5.9	5.6					6
Cr									
Al					5.9	5.7			
C	3.3	3.2	3.0	3.2	3.1	3.0			3
H	73.2	74.6	73.6	74.0	71.6	74.2			72
O	69.7	70.0	69.2	70.0	68.9	69.5			69

Cell Contents of the Hexagonal Polymorphs

								Theory
Mg	5.8	5.9	6.1	6.1	6.1	5.7	6.0	6
Fe	1.9	2.0	1.9					2
Cr								
Al				2.0	1.9	2.4	2.0	
C	1.1	1.0	1.1	1.1	1.0	1.0	1.1	1
H	24.7	24.4	24.7	24.3	25.2	24.8	24.9	24
O	23.2	23.0	23.4	23.4	23.6	23.6	23.6	23

1. Pyroaurite. Rutherglen, Ontario. Pure sample. Semi-micro analysis. Ellsworth (1939).
2. "Pyroaurite." Långban, Sweden. Known to be a mixture of pyroaurite and sjögrenite. Rem. is SiO_2. Johansson anal. in Aminoff and Broomé (1930).
3. "Pyroaurite." Långban, Sweden. Presumed to be a mixture of pyroaurite and sjögrenite. Rem. is insol. 0.39 and Mn_2O_3 0.28. Manasse (1915).
4. "Stichtite." Dundas, Tasmania. Presumed to be a mixture of stichtite and barbertonite. Recalculated to 100% after the deduction of SiO_2 2.09, and FeO 0.28 as chromite. Foshag (1920).
5. "Hydrotalcite." Kongsberg, Norway. Known to be a mixture of hydrotalcite and manasseite. Rem. is SiO_2. Foshag (1920).
6. "Hydrotalcite." Snarum, Sweden. Presumed to be a mixture of hydrotalcite and manasseite. Rem. is insol. Manasse (1915).
7. Manasseite. Snarum, Sweden. Pure sample, but contains gibbsite. Rem. is SiO_2. F. A. Gonyer anal., October, 1940.
8. Manasseite. Analysis 7 recalculated to 100% after deduction of SiO_2 0.35, and gibbsite 6.38 (on basis of 6 Mg atoms per cell).

Crystallography. The crystallography of pyroaurite was first described by Sjögren (1894), who regarded the crystals from Nordmark as hexagonal with pyramidal hemihedry and calculated the ratio of $a:c=1:3.6072$ from $\{0001\}\wedge\{10\bar{1}1\}=76°30'$. The pyramidal hemihedry is based on the occurrence of a third order prism, probably $\{21\bar{3}0\}$, obliquely truncating the edges of $\{10\bar{1}0\}$. Observed forms are: $\{0001\}$, $\{10\bar{1}0\}$, $\{10\bar{1}1\}$, $\{21\bar{3}0\}$ (?). In 1900 Flink described a new find of pyroaurite at Långban, and distinguished what he termed two habits for the species. One type consisted of broad thin hexagonal plates flattened on $\{0001\}$ and bounded laterally by $\{40\bar{4}1\}$. The crystals of the second type were smaller, with $\{0001\}$, $\{02\bar{2}1\}$ and $\{10\bar{1}1\}$, and had a decided rhombohedral development. Both habits were referred to the same axes, with $a:c=1:1.6557$ from $\{0001\}\wedge\{40\bar{4}1\}=82°33'$.[2] The apparent hexagonal pyramid on the crystals earlier described by Sjögren from Nordmark was interpreted by Flink as equally developed positive and negative rhombohedra, which closely approximate in position $\{02\bar{2}1\}$ and $\{20\bar{2}1\}$ in his unit for the

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[2] Flink gives 81°33′ which his other measured angles, on crystals of the second type, indicate to be a misprint for 82°33′. Aminoff and Broomé (1930) remeasured several crystals and obtained 81°25′ and 81°22′. They accepted Flink's value and calculated $a:c=1:1.4574$.

Långban crystals. Morphological data are lacking for the other known occurrences of pyroaurite.

An x-ray study of the Långban pyroaurite was made by Aminoff and Broomé in 1930. They found that the material included both a rhombohedral and a hexagonal substance, and that these substances corresponded with the rhombohedral and hexagonal habits recognized by Flink. The two substances occur intimately intergrown, and almost all of the apparently homogeneous single crystals of pyroaurite afforded Laue and powder photographs with both hexagonal and rhombohedral diffraction effects. They found it impossible to establish the composition of either of the two substances, since there was no certainty that any of the existing analyses referred solely to one or the other of the two substances, and it was not feasible to examine by x-ray means sufficient material for a new analysis. They then assumed that the two substances were polymorphous, and an effort was made to determine the cell contents and analyze the structure. The following x-ray data were obtained (hexagonal coordinates):

	a_0	c_0	$a_0:c_0$
"Hexagonal pyroaurite"	3.097	15.56	1:5.024
"Rhombohedral pyroaurite"	3.089	23.23	1:7.520

In the calculation of the cell contents the CO_2 reported in the analyses was regarded as secondary, and the formula taken as $3Mg(OH)_2 \cdot Fe(OH)_3.3H_2O$. It was then found that the number of formula-units in the unit cells were 0.49 and 0.75 for the hexagonal and rhombohedral substances, respectively,—results which in themselves are out of the question. Efforts to detect greater axial periods were unsuccessful, and the suggestion was made that special properties of the structure factor suppressed all of the reflections corresponding to the real identity period in one or several directions. The assumption was then made that a_0 for the two substances should be doubled, giving $Z_{rh.}=1$ in the rhombohedral unit and $Z_{hex.}=2$, and an ingenious attempt based on so-called structural isomery was made to analyze the structures.

An x-ray Laue study of pyroaurite from Långban has also been reported by Comucci (1930), who says that the mineral is monoclinic, pseudo-hexagonal, with $a:b:c=0.84:1:2.60$ and $\beta=90°41'$. Cell dimensions are not given. These results may be due to a maladjustment of the crystal or to use of a deformed crystal.

Optical Data. The older optical data on pyroaurite are tabulated below. Hitherto it has not been known to which of the modifications of pyroaurite this data is pertinent, but the present study proves that the data for the Rutherglen mineral certainly, and for the other material presumably, relate to the rhombohedral modification.

Locality	ω	ε	Observed
Rutherglen, Ontario	1.560±0.003	1.543±0.003	Ellsworth (1939)
Långban, Sweden	1.565±0.003		Larsen (1921)
	1.562	1.529	Manasse (1915)
Southern Serbia	1.563	1.543±0.002	Meixner (1937)
Kraubat, Styria	1.567 (Na)		Meixner (1938)

Pleochroic, with ω yellow to brown, ε nearly colorless. Sometimes biaxial, with small 2*V* and variable.

New Data. Rhombohedral Pyroaurite. Type specimens of the transparent green pyroaurite from Rutherglen, Ontario, were examined through the kindness of Dr. H. V. Ellsworth. The morphology, optical properties and *x*-ray powder pattern (see Fig. 1) of this mineral proved to be identical with the characters of the so-called rhombohedral pyroaurite from Långban, as given by Flink, and by Aminoff and Broomé, and independently determined by the writer on specimens from the Flink collection. The Rutherglen mineral is entirely homogeneous and fresh, and the analysis by Ellsworth (column 1, Table 1) thus indicates the true composition of the rhombohedral species.

TABLE 2. ATOMIC CONTENTS OF SOME MULTIPLE PYROAURITE UNIT CELLS

		Atomic Contents of Cell				
Analysis (Rutherglen)	Atomic Quotient	Observed cell $a_0 = 3.095$ $c_0 = 23.27$	c_0 doubled	a_0 doubled	c_0 times eight, or a_0 and c_0 doubled	Theory
Fe_2O_3 23.37	Fe 0.293	Fe=0.73	1.5	2.9	5.85	6
MgO 35.84	Mg 0.889	Mg=2.2	4.4	8.9	17.7	18
H_2O 32.97	H 3.663	H=9.2	18.3	36.6	73.2	72
CO_2 7.30	C 0.166	C=0.41	0.83	1.66	3.3	3
MnO 0.01	O 3.492	O=8.71	17.4	34.8	69.6	69

An *x*-ray Weissenberg study was made of a single-crystal of the Rutherglen material. The lattice-type is rhombohedral and the cell dimensions are: $a_0 = 3.095$, $c_0 = 23.27$, in hexagonal coordinates. These data confirm the findings of Aminoff and Broomé. The cell contents calculated from the observed dimensions on the basis of Ellsworth's analysis prove to be irrational. Accepting the validity of the analysis and the specific gravity (=2.14), then the observed cell dimensions must be sub-multiples of the true cell. The cell contents calculated on the basis of simple multiples of the observed cell are listed in Table 2. Rational cell contents which satisfy the essential condition that the number of atoms of a given kind must be three or a multiple of three for the unit cell in hexagonal coordinates, are afforded by the following alternatives:

The observed a_0 and c_0 are half of the true values.
The observed c_0 is one-eighth of the true value.

The latter alternative must be excluded, since a [0001] period of 186 Å is extremely improbable, and the doubled cell, with $a_0 = 6.19$ and $c_0 = 46.54$, is indicated as the true cell.[3] However, no evidence was found on strongly over-exposed Weissenberg, rotation or powder photographs of a multiple cell, nor did Aminoff and Broomé find evidence of a multiple cell. The space group of the pseudo-cell as found by the Weissenberg method is $R3m$, $R\bar{3}m$ or $R32$. The cell contents on the basis of the doubled cell in hexagonal coordinates are $Mg_{18}Fe_6(OH)_{48}(CO_3)_3 \cdot 12H_2O$, and the simplest formula for the mineral is

$$Mg_6Fe_2(OH)_{16}CO_3 \cdot 4H_2O \cdot$$

This formula is identical with that earlier derived by Manasse (1915) and Foshag (1920).[4] It may be noted that all of the creditable analyses of "pyroaurite" are very close to the above formula, in spite of the fact that all of the analyses presumably, and analyses 2 and 3 in Table 1 certainly, represent mixtures. This is due to the fact that the admixed materials, as shown beyond, are polymorphous modifications.

The physical and other properties of rhombohedral pyroaurite need not be treated here. The forms $\{02\bar{2}1\}$ and $\{10\bar{1}1\}$ observed by Flink on crystals from Långban become $\{01\bar{1}5\}$ and $\{20\bar{2}5\}$, respectively, in the doubled structural unit. Transformation

Flink to Frondel 0100/1000/0010/0005.

The name to be given to this mineral presents a problem, since the true symmetry of the original pyroaurite described by Igelström from Långban is unknown. The name pyroaurite is here arbitrarily restricted to the rhombohedral modification. Localities known definitely to afford (rhombohedral) pyroaurite include Långban, Sweden; Rutherglen, Ontario; Kraubat, Styria, Germany; Medenikamen and Belikamen, Serbia; Val Malenco and Val Ramazzo, Italy; and Blue Mont, Maryland. At Blue Mont, the first locality in the United States, the mineral occurs as a flaky coating on a joint plane in serpentine.

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[3] It may be remarked that Aminoff and Broomé obtained rational cell contents with $Z = 3$ for their formula for a cell of one-half the volume here required. This is due to the circumstance that, by mere chance, their formula had a molecular weight almost exactly one-half that of the formula here accepted.

[4] An alternative but much less probable interpretation of the composition of pyroaurite which does not require multiplication of the observed cell edges may be mentioned. The mineral may be represented as having a defect structure in point of CO_3 content with a compensating amount of Fe^3 substituting for Mg. The formula may be written as $(Mg, Fe_x)_3(OH)_6(CO_3)_{x/2} \cdot 1\frac{1}{2}H_2O$, where $x = ca.\ 0.75$ and $Mg:Fe = 3:1$.

The hexagonal mineral commonly admixed with pyroaurite is described on a following page under the name sjögrenite.

HYDROTALCITE

Historical. Hydrotalcite occurs only as foliated and contorted platy to fibrous masses, The mineral was originally described from Snarum, Norway, by Hostetter in 1842, who regarded the considerable amount of CO_2 in his analysis as due to alteration and considered the mineral an aluminate. J. D. Dana (1850) and Hermann (1847) rightly placed the mineral near brucite. Four analyses of the Snarum mineral by Rammelsberg (1859) also recorded large and rather constant amounts of CO_2, which were ascribed to admixed basic magnesium carbonate. A similar mineral was described by Hermann (1847) from Slatoust, in the Urals and regarded as a distinct species under the name voelknerite. Later, Hermann (1849) and also Rammelsberg (1856) urged the identity of this mineral with the Snarum material. The CO_2 reported in one of the analyses of the voelknerite was again ascribed to admixture. A probable third occurrence of hydrotalcite was recognized by J. D. Dana (1851), who pointed out that the supposed species houghite, described by Shepard (1851) from Somerville, New York, was a mixture of the so-called voelknerite and spinel. Analyses of this material by Johnson (1851) and by Root (1868) are of little value. An analysis of material from a new occurrence at Nordmark, Norway, was given by Foshag in 1920.

The validity of the species hydrotalcite itself was questioned by Kenngott (1866), who considered the material from both Snarum and Slatoust as a mixture of gibbsite, magnesite and brucite. Later writers, including Tschermak (1905), Zirkel (1898) and Bauer (1904) also held that the material was a mixture, probably of gibbsite and brucite, and this view was taken as highly probable by Hintze (1910). The species rank of the mineral was established by Manasse, in 1915, who contributed four new analyses together with dehydration and optical data and derived the formula:

$$Mg_6Al_2(OH)_{16}CO_3 \cdot 4H_2O \cdot$$

Manasse proved that the CO_2 was constitutional, and showed that hydrotalcite was the aluminum analogue of pyroaurite. It may be remarked, however, that J. D. Dana (1868) earlier considered that pyroaurite was the ferrian analogue of hydrotalcite, and that Igelström (1865) and Groth (1889) believed that the two species were isomorphous. Also, Himmelbauer (1913) had stated his belief that hydrotalcite was the aluminum analogue of the chromium mineral stichtite, and, earlier, Petterd (1910) considered stichtite to be the chromium analogue of pyroaurite. Both of these writers, and also Hezner (1912), admitted the constitutional role of the CO_2. Foshag, in 1920, similarly concluded that the CO_2 was constitutional and that stichtite, hydrotalcite and pyroaurite all had the same general formula, $Mg_6R_2(OH)_{16}CO_3\cdot 4H_2O$, where R = Cr, Al or Fe. Recently, analyses of hydrotalcite of undemonstrated homogeneity from Snarum, and from a new locality at Bashenowo in the Urals, have been reported by Kurnakov and Černych (1928). They state the formula of hydrotalcite as $Mg_9Al_4(OH)_{24}(CO_3)_3\cdot 8H_2O$ and give an analogous formula for pyroaurite. The analyses and dehydration data of these workers are out of line with the results of others.

Optical Data. The older optical data for hydrotalcite are summarized below. The data apparently refer to the rhombohedral polymorph of hydrotalcite described beyond.

Locality	ω	ε	Observer
Snarum, Norway	1.516±0.003	1.504±0.003	Larsen (1921)
	1.511	1.494	Manasse (1915)
	Birefringence	=0.0152	Kurnakov and Černych (1928)
Bashenowo, Urals	Birefringence	=0.0148	Kurnakov and Černych (1928)
Kongsberg, Norway	1.510±0.003	1.495±0.003	Larsen (1921)
	1.510		Foshag (1920)
St. Lawrence Co., New York	1.511±0.003	1.496±0.003	Larsen (1921)

The material from Bashenowo and Slatoust is said by Kurnakov and Černych (1928) to be optically positive; this may refer to the sign of elongation and not to the optical character, which in an OH-layer-lattice of the present type should be negative. Michel-Lévy and Lacroix (1888) give the average index (for Na) as 1.47, birefringence = 0.014, for the material from Snarum.

New Data. Rhombohedral Hydrotalcite. An *x*-ray powder and optical study was made of hydrotalcite from Somerville and Amity, New York, of the specimen from Kongsberg analyzed by Foshag (1920), and of five specimens from Snarum, Norway. The *x*-ray study showed that all of the specimens with the exception of the material from Somerville were intimate mixtures of a hexagonal substance with a rhombohedral material identical in pattern with rhombohedral pyroaurite (Figs. 1, 2). The mineral from Somerville gave a purely rhombohedral pattern. The de-

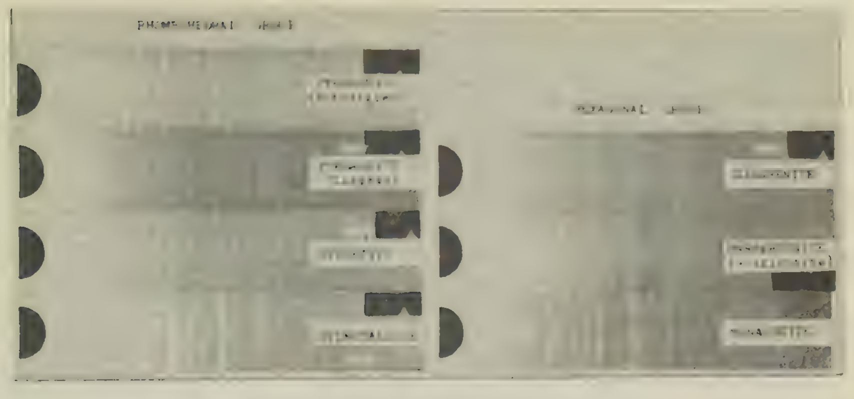

FIG. 1. *X*-ray powder photographs of members of the pyroaurite and sjögrenite groups.

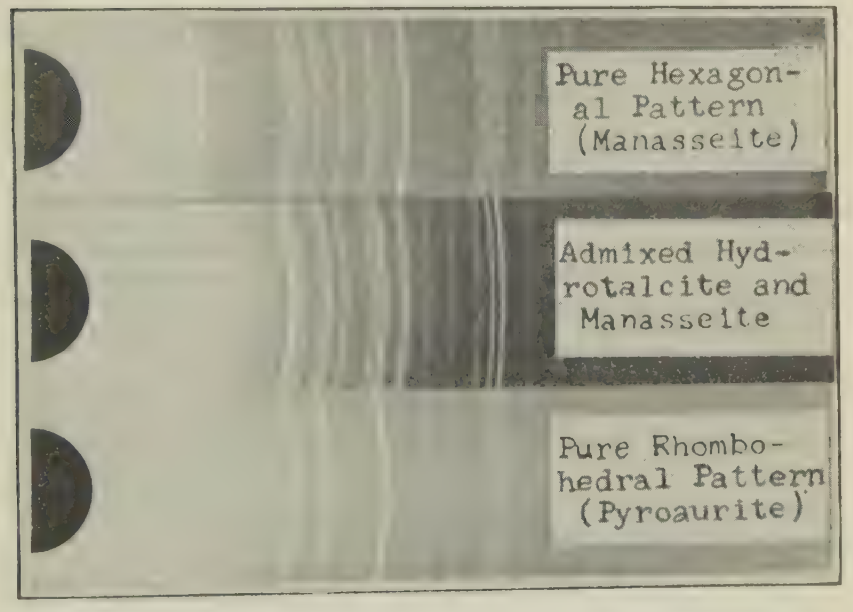
Pure Hexagonal Pattern (Manasseite)
Admixed Hydrotalcite and Manasseite
Pure Rhombohedral Pattern (Pyroaurite)

FIG. 2. *X*-ray powder photographs of admixed and pure members.

gree of admixture varies in different specimens from the same locality and in different parts of the same specimen, but the rhombohedral substance usually predominates greatly. Correlated optical and *x*-ray study gave the following optical data: The rhombohedral substance has $\omega = 1.510$ to 1.518 and $\epsilon = 1.495$ to 1.502, in part biaxial due to strain with small 2V, varying to 0° in the same flake. These values are very close to those cited in the literature for "hydrotalcite." The hexagonal substance had $\omega = 1.524$ and $\epsilon = 1.510$, in part biaxial with small 2V and variable. Optical evidence of admixture is difficult to establish, apparently because the hexagonal and rhombohedral substances occur together as submicroscopic flakes interlaminated on {0001}, but was definitely proven in several specimens.

The *x*-ray powder pattern of the rhombohedral substance is identical with that of rhombohedral pyroaurite, aside from a slight difference in cell dimensions (Figs. 1, 2). The dimensions calculated from the powder pattern are: $a_0 = 3.065$, $c_0 = 23.07$, in hexagonal coordinates. The composition of the mineral can not be fixed directly, since none of the analyses of hydrotalcite are definitely known to have been made on a homogeneous rhombohedral sample. The following evidence, however, establishes with reasonable certainty the formula

$$Mg_6Al_2(OH)_{16}CO_3 \cdot H_2O$$

for the mineral, analogous to the formula of pyroaurite:

1. The *x*-ray data indicates that the mineral is isostructural with pyroaurite. The slightly smaller cell dimensions correspond to the substitution of Al for Fe.
2. Analyses of samples known or presumed to be mixtures, specifically including the Kongsberg material analyzed by Foshag, which is found by *x*-ray study to be a mixture in almost equal proportions of the two substances, yield a formula with the identical ratio of pyroaurite. This also is presumptive evidence of the polymorphic relation of the hexagonal and rhombohedral substances. The cell contents calculated for two of the creditable analyses are given in columns 5 and 6, Table 1, and are in close accord with the formula given above. The doubled cell, with $a_0 = 6.13$, $c_0 = 46.15$, is again required.

The symmetry of the original hydrotalcite of Hostetter (1842) from Snarum is unknown, and the name hydrotalcite is here arbitrarily restricted to the rhombohedral modification. The hexagonal substance commonly admixed with hydrotalcite is described on a following page under the name manasseite.

STICHTITE

Historical. Stichtite occurs only massive, as aggregates of fibers or plates, often matted or contorted, and as cross-fiber veinlets. The mineral was originally described from Dundas, Tasmania, by Petterd in 1910, and was analyzed by Wesley (in Petterd, 1910) and later by Hezner (1912) and Foshag (1920). Hezner, unaware of the work of Petterd, described her material as a new species, chrombrugnatellite. Himmelbauer (1913) later showed the identity of Hezner's mineral with stichtite. A second occurrence of the mineral, near Barberton in the Transvaal, was described by A. L. Hall (1922) with an analysis by McCrae and Weall. Recently a third occurrence, at Cunningsburgh, Shetland Islands, Scotland, was described and analyzed by Read and Dixon (1933). Stichtite also has been found at the Megantic mine, Black Lake, Quebec, by Poitevin and Graham (1918), but analyses are lacking.

Stichtite occurs intimately admixed with chromite and serpentine and unquestionably homogenous material has not yet been analyzed. Petterd derived the formula $5Mg(OH)_2 \cdot MgCO_3 \cdot 2(Cr,Fe)(OH)_3 \cdot 5H_2O$, but the $MgO:(Cr,Fe)_2O_3$ ratio of his analysis is closer to 7:1 than 6:1. Hezner obtained the formula $5Mg(OH)_2 \cdot 2MgCO_3 \cdot 2Cr(OH)_3 \cdot 4H_2O$ after the deduction of 16.49 per cent impurity. Foshag, working on material stated to be homogeneous except for admixed chromite (although the analysis contains 2.09 per cent SiO_2, suggesting the presence of serpentine), obtained the formula $5Mg(OH)_2 \cdot MgCO_3 \cdot 2Fe(OH)_3 \cdot 4H_2O$, analogous to the formula derived by him for pyroaurite and hydrotalcite. Hall (1922) doubted that the mineral had a definite composition. Read and Dixon recalculated their analysis and the earlier analyses after deducting SiO_2 as serpentine and FeO as chromite, $FeCr_2O_4$. On this basis all of the analyses agree fairly well with the formula $5Mg(OH)_2 \cdot MgCO_3 \cdot Mg[CO_3(OH)_2] \cdot 2(Cr,Fe)(OH)_3 \cdot 4H_2O$. However, no great confidence can be placed in this or in the other formulae proposed in view of the uncertainity as to the composition and amount of the impurities present. This is particularly true of the admixed chromite, which while assigned the formula $FeCr_2O_4$, for the purposes of the calculation, actually in nature is usually both highly magnesian and ferrian. A considerable error in this respect may be introduced in the analysis of the Cunningsburgh mineral, which as recalculated by Read and Dixon contains 27.89 per cent chromite as $FeCr_2O_4$ and but 45.97 per cent stichtite. Hezner deducted from her analysis 11.23 per cent serpentine as $H_4Mg_3Si_2O_9$, although her separate analysis of the serpentinous rock forming the matrix of the specimen contains FeO above any interpretation of the Cr_2O_3 as chromite, and otherwise differs considerably from the formulae given. A similar objection can be raised against the deduction of serpentine as $H_4Mg_3Si_2O_9$ in the recalculation by Read and Dixon of the stichtite from Barberton, as a separate analysis of the serpentinous matrix of the stichtite shows it to be highly ferruginous.

Optical Data. The older optical data for stichtite are tabulated below. It is shown beyond that the data for the Dundas mineral refer to rhombohedral stichtite, and that the data for the Cunningsburgh material probably refer to the hexagonal polymorph, barbertonite.

Locality	ω	ϵ	Observer
Dundas, Tasmania	1.542	1.516	Himmelbauer (1913)
Cunningsburgh, Scotland	1.559 (Na)	1.543 (Na)	Read and Dixon (1933)

Faintly pleochroic in violet, with absorption $\omega > \epsilon$. Elongation positive. In part biaxial with small 2V and variable.

New Data. Rhombohedral Stichtite. Stichtite from Dundas, Tasmania, from Black Lake, Quebec, and from the Barberton district, Transvaal, was examined by optical and x-ray methods. The x-ray study showed that the Dundas and Barberton materials were intimate mixtures of a hexagonal substance with a rhombohedral substance identical in pattern with (rhombohedral) pyroaurite and hydrotalcite (Fig. 1). The material from Black Lake was composed solely of the rhombohedral substance. The material from Dundas was composed very largely of the rhombohedral substance, and optically some samples were homogeneous with $\omega = 1.545$, $\epsilon = 1.518$, in part biaxial due to strain with small and variable 2V. These indices are very close to those given by Himmelbauer for the material from Dundas analyzed by Hezner. The Barberton material was largely composed of the hexagonal substance. Optically it consists mostly of a mineral with $\omega = 1.557$, $\epsilon = 1.529$, with a portion of the material having ω about 1.547. The latter value evidently represents the admixed rhombohedral substance. The material with the higher indices apparently corresponds to the so-called stichtite from Cunningsburgh, Scotland, described by Read and Dixon (1933). Material from this locality was not available for study.

The cell dimensions of the rhombohedral substance as obtained from a powder photograph are: $a_0 = 3.09$, $c_0 = 23.19$ in hexagonal coordinates. The composition of the mineral can not be established directly, since none of the analyses of so-called stichtite are known to refer solely to the rhombohedral modification. The isostructural relation to hydrotalcite and pyroaurite indicated by the x-ray data, however, makes it reasonably certain that rhombohedral stichtite is the chromium member of the group with the formula:

$$Mg_6Cr_2(OH)_{16}CO_3 \cdot 4H_2O.$$

The cell contents calculated on the basis of the doubled cell ($a_0 = 6.18$, $c_0 = 46.38$) for the analysis of the Dundas material by Foshag are given in Table 1, column 4, and are fairly close to the requirements of the formula indicated above.

The original stichtite of Petterd (1910) came from Dundas, Tasmania, and the name stichtite is conveniently retained to refer to the rhombohedral modification, which predominates at this locality. The hexagonal substance commonly admixed with stichtite is described on a later page under the name barbertonite.

HEXAGONAL OR SJÖGRENITE GROUP

SJÖGRENITE

Broad plates of so-called pyroaurite from Långban with the hexagonal habit, recognized by Flink (1900) and by Aminoff and Broomé (1930), were examined by the Laue method and found to be hexagonal. The interior portion of large flakes had $\omega = 1.573 \pm 0.003$, $\epsilon = 1.550 \pm 0.005$, but the indices varied somewhat, especially toward the margins of the plates. The indices are notably higher than those of rhombohedral pyroaurite. The x-ray powder photograph of a homogeneous sample was indexed in terms of a hexagonal cell with the dimensions: $a_0 = 3.10$, $c_0 = 15.57$. These dimensions are identical with those for the hexgaonal substance recognized by Aminoff and Broomé. Optical or other evidence which definitely associates any of the reported analyses of so-called pyroaurite with the hexagonal substance is lacking. The following evidence, however, indicates that the hexagonal substance has the formula:

$$Mg_6Fe_2(OH)_{16}CO_3 \cdot 4H_2O$$

and hence is polymorphous with pyroaurite:

1. The mineral is found by x-ray study to be isostructural with the hexagonal minerals manasseite and barbertonite, described beyond, which occur associated with hydrotalcite and stichtite, respectively. A new analysis of manasseite and indirect evidence for both manasseite and barbertonite indicate that they have the general formula $Mg_6R_2(OH)_{16}CO_3 \cdot 4H_2O$ and are polymorphous with hydrotalcite and stichtite. The isostructural relation to these minerals indicates that the hexagonal substance here described has the same general formula.
2. Unit cell contents expressing the formula given above are afforded by Johansson's analysis of a sample from Långban known to be a mixture of the hexagonal substance and pyroaurite, by Manasse's and other creditable analyses of the Långban material (which can be presumed to represent mixtures) and by the analysis of Ellsworth on the pure Rutherglen pyroaurite (see columns 2 and 3, Table 1). This is presumptive evidence both of the correctness of the formula and of the polymorphic relation of the hexagonal substance to pyroaurite. Rational cell contents, however, are afforded only when the observed a_0 is doubled ($=6.20$).

The name sjögrenite is proposed for the mineral here described in honor of Hjalmar Sjögren (1856–1922), Swedish mineralogist and formerly Professor of Mineralogy at the University of Stockholm, who described the occurrence of so-called pyroaurite at Nordmark, Sweden. The properties of sjögrenite are as follows: Hexagonal; structure cell $a_0 = 6.20$, $c_0 = 15.57$. Crystals are broad basal plates bounded laterally by striated and indistinct pyramids or a prism. Hardness = $2\frac{1}{2}$. Specific gravity = 2.11 (observed), 2.11 (calculated). Uniaxial negative, with $\omega = 1.573$, $\epsilon = 1.550$. Color creamy white, yellowish, nearly colorless; luster on cleavages pearly. Known only from Långban, Sweden, where it occurs mostly in parallel growths with pyroaurite.

MANASSEITE

The hexagonal substance recognized in the x-ray powder photographs of hydrotalcite from Snarum and Kongsberg, Norway, and Amity, New York, has a pattern identical with those of sjögrenite and the chromium mineral barbertonite, described beyond. The observed cell dimensions are: $a_0 = 3.06$, $c_0 = 15.34$. One of the specimens from Snarum was almost entirely free from admixture with hydrotalcite and was analyzed by Mr. F. A. Gonyer (column 7, Table 1). Under the microscope this material was found to contain minute embedded grains of a mineral identified with some certainty as gibbsite, and rare grains of diaspore and an unidentified mineral. The cell contents calculated for this analysis are in satisfactory agreement with the formula:

$$Mg_6Al_2(OH)_{16}CO_3 \cdot 4H_2O \cdot$$

It is necessary, however, to double the observed value of a_0, as with sjögrenite. The agreement with the formula becomes very close if the analysis is recalculated after the deduction of 6.38 per cent gibbsite (column 8, Table 1). The analysis by Foshag (1920) of the so-called hydrotalcite from Kongsberg, which is found on x-ray study of the analyzed specimen to represent a mixture in almost equal proportions of hydrotalcite and the hexagonal substance here described (see Fig. 2), also affords cell contents (column 5, Table 1) in satisfactory agreement with the formula cited above. These facts indicate with reasonable certainity that the mineral is identical in composition with hydrotalcite.

The name manasseite is proposed for this mineral in honor of Ernesto Manasse (1875–1922), Italian chemist, mineralogist and petrographer, formerly Professor of Mineralogy at the University of Florence, who made important contributions to our knowledge of hydrotalcite and pyroaurite. The properties of manasseite are as follows: Hexagonal; structure cell: $a_0 = 6.12$, $c_0 = 15.34$. Occurs as contorted lamellar-fibrous masses. Perfect cleavage {0001}. Hardness 2. Specific gravity 2.05 ± 0.05 (observed), 2.00 (calculated). Color white to bluish white, with a pearly luster on the cleavages. Uniaxial negative, with $\omega = 1.524$, $\epsilon = 1.510$, and in part biaxial due to strain with small 2V varying to 0° in the same flake.

BARBERTONITE

The hexagonal substance recognized in the *x*-ray powder patterns of stichtite from Dundas, Tasmania, and Barberton, Transvaal, is identical in pattern with sjögrenite and manasseite (Fig. 1). The cell dimensions are: $a_0=3.085$, $c_0=15.52$. Analyses known to refer only to the hexagonal substance are lacking, but the isostructural relation to sjögrenite and manasseite indicates that the mineral is the chromium member of the hexagonal group with the formula:

$$Mg_6Cr_2(OH)_{16}CO_3 \cdot 4H_2O$$

and is polymorphous with stichtite. The indices of the mineral ($\omega=1.557$, $\epsilon=1.529$) are very close to those of the so-called stichtite from Cunningsburgh, Scotland, and the analysis by Read and Dixon (1933) of this material may represent the hexagonal substance. While neither this analysis nor the analysis cited by Hall (1922) for the Barberton material is satisfactory, due to gross admixture with serpentine and chromite as previously discussed, the ratios derived from them are fairly close to those of the formula given above. The cell contents (column 4, Table 1) calculated on the basis of the analysis by Foshag (1920) of the (admixed) material from Dundas, also are close to the formula given. The observed a_0 must again be doubled to give rational contents, as in the case of sjögrenite and manasseite.

The name barbertonite is proposed for the mineral after the occurrence in the Barberton district, Transvaal. The properties of barbertonite are as follows: hexagonal; structure cell: $a_0=6.17$, $c_0=15.52$. Occurs as contorted lamellar-fibrous masses and as cross-fiber veinlets. Hardness $=1\frac{1}{2}$–2. Specific gravity $=2.10\pm0.05$ (observed), 2.11 (calculated). Perfect cleavage $\{0001\}$. Color rose-pink to violet. Uniaxial negative, with $\omega=1.557$, $\epsilon=1.529$, and in part biaxial due to strain with small and variable 2V.

MODE OF INTERGROWTH OF THE POLYMORPHS

Sjögrenite occurs at Långban as oriented growths upon pyroaurite, with sjögrenite $\{0001\}$ $[10\bar{1}0]$ parallel pyroaurite $\{0001\}$ $[10\bar{1}0]$. An *x*-ray study of the growths is given by Aminoff and Broomé (1930). Pyroaurite occurs analogously oriented upon brucite at Kraubat, Styria (Meixner, 1938). The a_0 values of pyroaurite ($=6.19$), sjögrenite ($=6.20$) and brucite ($3.12\times2=6.24$) are nearly alike, and the mutual orientation doubtlessly is conditioned by a near identity in arrangement and spacing of the OH ions in the $\{0001\}$ layers.

Manasseite and barbertonite commonly occur admixed with their rhombohedral analogues, and the existence of a mutual orientation similar to that between sjögrenite and pyroaurite was sought by an x-ray Laue examination of cleavage flakes of the intergrowths. A very unusual mode of association was found. The hexagonal and rhombohedral analogues appear to consist of microscopic or submicroscopic plates interlaminated on {0001} with a partially or completely random stacking of the plates about [0001]. This arrangement is deduced from Laue photographs such as are shown in Fig. 3. in which the complete circles are found to be loci of reflection of single planes (spots) on normal single-crystal Laue photographs taken along [0001]. Figure 3, right, shows a partially random stacking in a mixture composed largely of barbertonite. A completely random stacking about [0001] was found in a cleavage flake composed entirely of manasseite. The pyroaurite from Rutherglen gives a perfect single-crystal photograph, without asterism or circles.

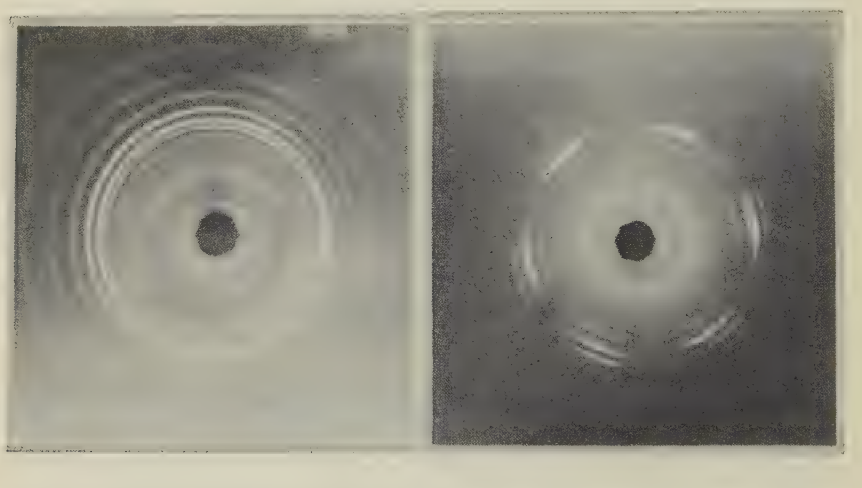

FIG. 3. Laue photographs taken along [0001] of cleavage flakes of manasseite (left) and of a barbertonite-stichtite intergrowth (right). Fe radiation.

The origin of the random character of the intergrowths is difficult of explanation. The occurrence of the minerals as more or less contorted masses in serpentine suggests that mechanical deformation has been effective. It is also obscure why the polymorphs should so commonly occur together in the first place. The extended laminar character of the intergrowths and the relatively large development of surface between the two phases makes it seem improbable that the association represents an incomplete polymorphic inversion. Possibly the association is primary, and the appearance of one or the other modification over brief periods of time during crystallization may be a chance phenomenon involving a choice between closely related structures of essentially equal thermodynamic stability. The polymorphism presumably arises in differences in the manner or period of stacking of hydroxide layers (i.e., OH-cation-OH layers) along [0001]. A brucite-like arrangement almost certainly constitutes one of the layer motifs. The mutual association possibly unites the structure of the two phases in such a manner that identical layers adjoin, defining a virtual third phase in the contact region. This may be a brucite block of structure in the present instance. The virtual contact phase possibly insulates, and maintains a zero interfacial energy between, the two polymorphs proper and prevents transformation.

BRUGNATELLITE

Brugnatellite was originally described and analyzed by Artini (1909) from the Val Malenco, Lombardy, Italy. Later, the mineral was reported by Pelloux (1913) and analyzed by Artini (1922) from Monte Ramazzo, Liguria, Italy. A third occurrence of the mineral, at Viu, Val di Lanzo, Piedmont, Italy, was analyzed by Fenoglio (1927), and an analysis of an additional occurrence, at Cogne, Val d'Aosta, Italy was reported by Fenoglio (1938). Brugnatellite is said by Larsen and Goranson (1932) to occur at Iron Hill, Colorado, but no description is given.

Both Artini and Fenoglio recognized the constitutional role of the CO_2, and deduced the formula:

$$Mg_6Fe(OH)_{13} \cdot CO_3 \cdot 4H_2O.$$

This formula differs from that of pyroaurite and sjögrenite in containing one-half as much Fe^3. In 1938 Fenoglio described an x-ray Laue and powder study of brugnatellite. He obtained a hexagonal (trigonal) cell with $a_0 = 5.47$ and $c_0 = 15.97$, and with $Z = 0.97 \sim 1$ on the basis of the formula given above. The optical data for brugnatellite are tabulated below.

Locality	ω	ϵ	Observer
Val Malenco, Italy	1.533 (Na)		Artini (1909)
	1.535		Larsen (1921)
Monte Ramazzo, Italy	1.540±0.003	1.510±0.005	Larsen (1921)
	1.536		Foshag (1920)
	1.536		Artini (1922)
Val di Lanzo, Italy	1.537±0.001 (Na)		Fenoglio (1927)

Pleochroic, with ω yellowish red and ϵ colorless.

New Data. Type brugnatellite was not available for study. A specimen labeled brugnatellite from the original locality in the Val Malenco proved to be an intimate mixture of a pale yellow uniaxial negative mineral with $\omega = 1.535$ to 1.540 (brugnatellite ?) with artinite, chrysotile, hydromagnesite, brucite and abundant pyroaurite. The x-ray powder pattern was largely that of pyroaurite, with additional lines due to admixture. Three specimens labelled brugnatellite from Monte Ramazzo were also examined and proved on x-ray and optical study to be mixtures largely of pyroaurite and brucite.

The possibility suggested itself that the pyroaurite in the specimens actually is brugnatellite, and that this species is isostructural with pyroaurite with a defect lattice in point of Fe^3 content. The fact that pyroaurite has not been previously reported from these localities encourages this view—granting the authenticity of the specimens. However, the Laue data given for brugnatellite by Fenoglio (1938), who appears to have used analyzed type material, show that the lattice mode is primitive hexagonal, and in this differs from the centered (rhombohedral) lattice of pyroaurite, while the point-symmetry is trigonal, and in this differs from the hexagonal mineral sjögrenite. The cell dimensions and powder patterns also are unlike, as are the indices of refraction. Further, the four analyses of brugnatellite, from four different localities, uniformly show a Fe^3 content one-half that of pyroaurite and sjögrenite. This fact, however, is not rigorous evidence against a defect lattice, although it is true that uniformly simple and numerically small ratios between occupied and vacant positions are generally lacking in defect structures as commonly defined. The conclusions seem forced that brugnatellite is a distinct species from pyroaurite and sjögrenite, and that pyroaurite occurs associated with brugnatellite at Val Malenco and Val Ramazzo.

Two additional carbonate-hydroxides of Mg and Fe were recognized in the course of the present study as new and different from the minerals at hand, and the mineralogy of the magnesium carbonate-hydroxides appears to be complex. The ill-defined pyroaurite-like materials described by Heddle (1878) from Haaf-Grunay and by Sjögren (1894) from Nordmark, and the so-called hydrotalcite from Slatoust and Bashenowo also may represent distinct species.

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PETROFABRIC RELATIONS OF NEPHELINE AND ALBITE IN LITCHFIELDITE FROM BLUE MOUNTAIN, ONTARIO

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Abstract

Petrofabric analysis of a specimen of litchfieldite from Blue Mountain, Ontario, shows: (1) Foliation and lineation expressed principally by elongate tabular albite crystals; (2) (010) of albite parallel to the foliation; (3) c_v of nepheline and albite approximately parallel to each other and to the lineation. This orientation is interpreted as the result of normal igneous crystallization; in the case of the earlier albite from flowing magma, in the case of the later nepheline from stagnant residual liquid.

Introduction

Although previous petrofabric studies of albite have been made (1) there is no published information concerning the orientation of nepheline. The abundance of the latter mineral in the Blue Mountain alkaline rocks recently studied by Keith (2) led to a search for material suitable for petrofabric analysis. In most specimens of such rocks there are too few grains of nepheline per thin section to make a statistical analysis practicable unless a number of successive parallel sections are prepared. Commonly the grains are highly altered and unsatisfactory for orientation work. Also, foliation and lineation may not be discernible and interpretation of the orientation is thus made hazardous. One of the Blue Mountain specimens met these difficulties successfully and was made available to me by Keith for petrofabric analysis. The data presented here are not in any way final, but it was thought advisable to present the existing information rather than withhold publication indefinitely during the search for more material.

Mineralogy and Geological Relations of the Litchfieldite

Litchfieldite is a medium-grained, leucocratic nepheline rock in which potash feldspar makes up less than one-half the total feldspar.[1] The average modal proportions of the three principal minerals in the Blue Mountain variety are: microcline 20%, nepheline 22%, albite 54%. The rock forms an irregular, oval stock one and one-half by three miles in its greatest surface dimensions, with a long narrow projection extending two and one-quarter miles from one end. It is intrusive into hornblende-biotite schist. Both invaded and invading rocks are of pre-Cambrian age.

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[1] Such rocks are erroneously called nepheline syenite. The potash feldspar in true nepheline syenite amounts to more than one-half the total feldspar (2).

The long axis of the outcrop of the litchfieldite strikes about N30°E, parallel to the regional trend. Dips at the borders of the main stock are 60°–70° inward. Foliation is conspicuous only in places near the contacts. The poorly developed lineation, where observed, is approximately horizontal.

The litchfieldite is uniformly medium-textured. Albite is more coarsely crystallized than microcline and nepheline and occurs in unzoned, subhedral crystals. It has abundant albite twins and an anorthite content of less than 5%. Nepheline is interstitial to albite and microcline and in part follows their grain boundaries. In places it forms intergrowths with albite which are of replacement origin. All the minerals are clear and unaltered.

PETROFABRIC ANALYSIS

The specimen selected for statistical analysis shows both lineation and foliation. These structural elements are largely due to the predominant albite, which occurs for the most part in inequant grains. These have a tabular habit which gives rise to a rude foliation, and in addition are elongate, producing a visible lineation. Two thin sections were studied, one perpendicular to the lineation, and one parallel to it, both being perpendicular to the foliation. Figures 1, 2, and 3 are collective diagrams oriented parallel to the lineation *b*, and show the results of measurements made on these sections. The foliation *s*, drawn as a great circle about 6° from the center of the figures, indicates that the section was not cut exactly perpendicular to *s*.

The most conspicuous orientation is shown in Fig. 1, where the poles to (010) planes of albite have an average position about perpendicular to the observed *s*-surface in the specimen. Figure 2 shows the orientation of the optic direction β in the same albite grains. The chief concentrations are at the margin of the diagram approximately 90° from the (010) pole maximum of Fig. 1. If *s* is taken as the average (010) plane, then for albite the two chief directions of β are as shown.[2] The crystallographic axis c_v then lies midway between the two β positions, or parallel to the lineation of the rock. There is sufficient concentration of β adjacent to the two ideal positions in Fig. 2 to justify a relatively fixed position for c_v. This means that the (010) albite planes are not only parallel, but that there is a tendency for parallelism of the c_v directions contained in them. In terms of the dimensional orientation associated with this crystallographic orientation, (010) is statistically parallel to the foliation, and c_v is parallel to the lineation. This orientation is one of the commoner ones previously determined for albite (1).

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[2] Triclinic crystals (such as the plagioclase series) have four possible positions of any optic direction in terms of a fixed crystallographic plane. However, the optic-crystallographic relations in albite are such that for petrofabric work two of these four possible positions may be neglected. (For details consult any work on optical mineralogy.)

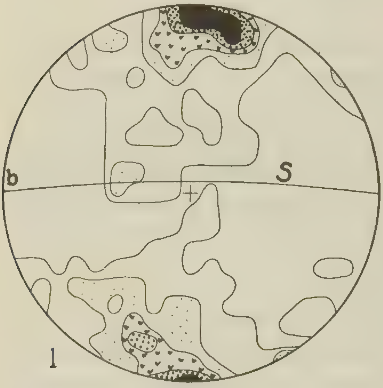

FIG. 1. Collective diagram of 110 poles to (010) of albite; *s*—foliation; *b*—lineation. Contours 9-7-5-3-1-0%.

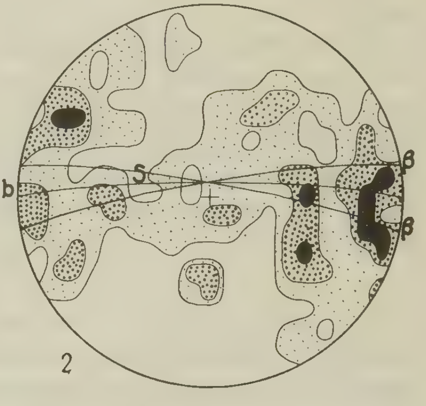

FIG. 2. Collective diagram of 110 β's of albite; *s* and *b* as in Fig. 1. The remaining two great circles show the orientation of the two significant β directions, assuming c_v is parallel to lineation *b*. Contours 5-3-1-0%.

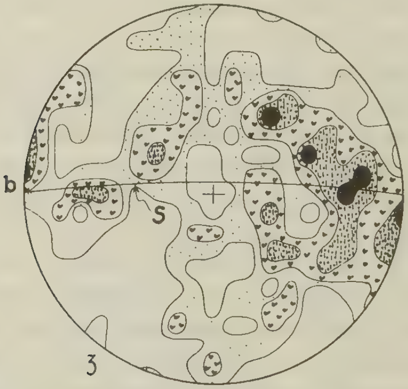

FIG. 3. Collective diagram of 254 vertical crystal axes c_v of nepheline; *s* and *b* as in Fig. 1. Contours 4-3-2-1-0%.

Figure 3 shows the orientation of the vertical crystal axes c_v of the nepheline interstitial to the albite and microcline. Although not very pronounced there is an indication that the axes prefer the *s*-surface in general and the lineation in particular as concentration areas. As with quartz, it is not possible by optic means to determine the precise orientation of the prism zone with respect to *s*.

The three diagrams indicate, in summary, that (010) of albite is parallel to the foliation and that c_v of both nepheline and albite tend to lie parallel to the lineation. In addition the dimensional orientation of albite is closely related to this crystallographic orientation, since the parallel tabular crystals form the foliation and the long dimensional axes c_v form the lineation.

Discussion of Orientation

As no systematic petrofabric study of the Blue Mountain intrusive was attempted, a lengthy discussion of the orientation just described would be futile. A few remarks can be made however without undue extrapolation of the facts. The prinicpal observation concerns the improbability that deformation played any part in producing the orientation. This is supported both by field and petrographic evidence (2). The crystallographic orientation of the albite and nepheline is not significant in this respect since nothing is known experimentally of the gliding elements of these minerals. The dimensional orientation of the albite is significant however and indicates that growth orientation resulting from normal igneous crystallization is probably the best hypothesis. Albite crystallized before nepheline and, with microcline (orientation undetermined), makes up almost 75% of the rock. The albite orientation is probably the result of magmatic flow, and the long axes of the tabular crystals may indicate the direction of flow. Details of the foliation and lineation in the litchfieldite are too meagre however to permit generalization about the magma movement on the evidence of the single specimen studied here.

The nepheline orientation is probably controlled by the pre-existing albite orientation. Since the greater part of the magma had already crystallized at the time of the nepheline precipitation, there would be no appreciable flow at this stage. The liquid from which the nepheline crystallized was thus essentially stagnant and the nepheline was not subjected to the orienting influence of flow. The tendency to parallelism of the vertical axes of nepheline and albite may therefore follow the law of minimum interfacial energy (3) used to explain parallel grouping of crystals and the orientation of inclusions in large single crystals. That is, the crystallizing nepheline seed-crystals tend to come to rest on the albite plates in that position which is most stable from the standpoint of interfacial energy. No study of oriented inclusions involving this particular pair of minerals has ever been made, but by analogy with other oriented inclusions some such mechanism may well explain the albite-nepheline relations in the Blue Mountain stock.

ACKNOWLEDGMENTS

I am indebted to M. L. Keith of Queen's University for the specimen used in this study and also for critical reading of the manuscript. I had also the advantage of discussing the problem with Clifford Frondel of Harvard University.

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3. FRONDEL, CLIFFORD, Oriented inclusions in muscovite etc.: *Am. Mineral.*, **25**, 69 (1940).

QUARTZ XENOCRYSTS IN OLIVINE BASALT FROM THE SOUTHERN SIERRA NEVADA OF CALIFORNIA

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ABSTRACT

Isolated bodies of volcanic rocks heretofore but little known and found in the southern Sierra Nevada are described. Olivine basalts containing well defined quartz xenocrysts are common. The hypothesis is advanced that the quartz is derived from the alteration of numerous inclusions of grandiorite in the volcanic rocks. Radial cracks about some inclusions are described, and an hypothesis for their origin is discussed.

INTRODUCTION

Field work has been carried on by the writer in the southern Sierra Nevada for the past seven years; an areal map of the Kernville quadrangle has been prepared[1] and certain special problems have been investigated.[2] The purpose of this paper is to describe quartz xenocrysts in basalt, and associated volcanic rocks of the southern Sierra Nevada, principally south of lat. 36°N.

SKETCH OF THE REGIONAL GEOLOGY

The rocks of the region consist of a series of phyllites, quartzites, and marbles, to which the name Kernville series has been applied;[3] these have been invaded by (1) gabbro, locally varying to diorite and quartz diorite, which is closely associated with (2) quartz diorite, varying to granodiorite. These are intermediate in age between the Kernville series and (3) the Isabella[4] granodiorite which has quartz monzonite, granite, and quartz diorite facies, and is believed to belong to the major intrusive period of Sierran orogeny, the late Jurassic.[5] Basalts and quartz-bearing basalts, with other associated volcanic types rest on erosional surfaces beveling these rocks. A few lacustrine and fluviatile sediments comprise the youngest rocks.

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[1] Miller, William J., and Webb, Robert W., Descriptive geology of the Kernville quadrangle, California: *Calif. Bur. Mines and Geol.*, in press.

[2] Webb, Robert W., Kern Canyon fault, Southern Sierra Nevada: *Jour. Geol.*, **44**, 631-638 (1936); Relations between wall rock and intrusives in the crystalline complex of the Southern Sierra Nevada of California: *Jour. Geol.*, **46**, 310–320 (1938).

[3] Miller, William J., Geologic sections across the southern Sierra Nevada of California: *Univ. Calif. Pub., Bull. Dept. Geol. Sci.*, **20**, 335 (1931).

[4] Miller, William J., *op. cit.*, 344.

[5] Hinds, N. E. A., The Jurassic age of the last granitoid intrusives in the Klamath Mountains and Sierra Nevada, California: *Am. Jour. Sci.*, **27**, 182–192 (1934).

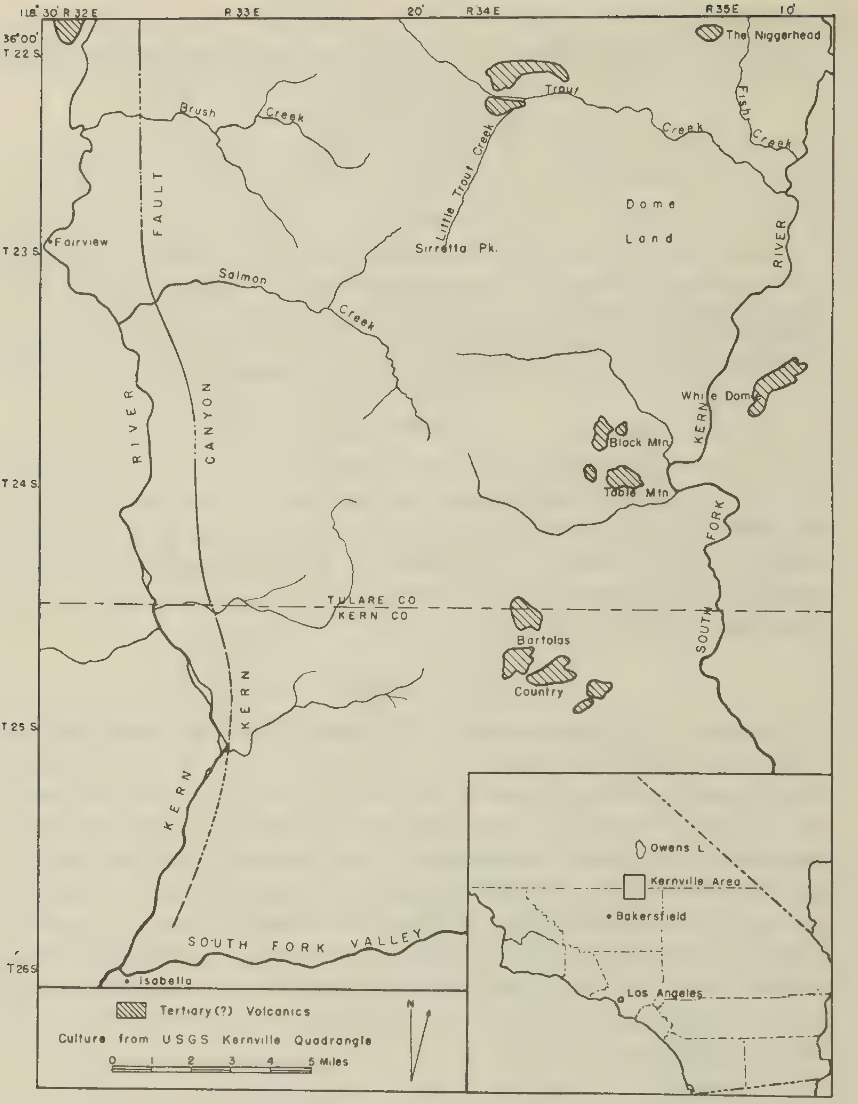

FIG. 1. Sketch map showing location of the Kernville area, and distribution of the volcanic sequences.

PREVIOUS REFERENCE TO VOLCANIC TYPES

In the Kernville region, Miller[6] reported the occurrence of a few small andesite dikes and waterworn pebbles of similar material in the valley of the South Fork of the Kern River. Lawson[7] described basaltic cones and flows in the Olancha quadrangle to the north, with a brief petrographic description of the volcanic rocks. Later Knopf[8] described the volcanic cones of Templeton and Monachee Meadows in the Olancha quadrangle.

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[6] Miller, William J., *op. cit.*, 353.

Description of the Volcanic Sequences

General Areal Relations

The volcanic rocks occur as flows in disconnected areas, all within the Kernville quadrangle and north of South Fork valley. They vary petrologically, in stratigraphic sequence, and structure. From south to north, the units may be designated as follows: (see Fig. 1)

(1) Bartolas. Volcanic rocks are exposed in five isolated areas. They rest on crystalline basement rocks which were previously reduced by erosion to the condition of an undulating oldland. The four southernmost of these probably were connected at one time, as indicated by their similar altitudes, compositions, thicknesses, structures, and areal patterns. They are uniform throughout, composed of platy, black basalt from 100–150 feet thick. The rocks in the fifth area, the northernmost of the Bartolas group, are black massive basalt, red banded basalt, and gray hornblende andesite, occurring in stratigraphic units in thicknesses of about 50 feet.

(2) Table Mountain. Two separated, but at one time continuous, flows, lie on an oldland surface north of the Bartolas country. These are composed of massive gray to black basalt, which is often agglomeratic at the base. Thicknesses are commonly 200 feet, but are thinner in the western of the two units.

(3) Black Mountain. Two areas, separated by erosion and closely adjacent to Table Mountain, are composed of scoriaceous red, and black massive basalt, occurring in several flows totaling 150–200 feet in thickness.

(4) White Dome. A single massive, black basalt flow represents the only volcanic rock in the region east of the South Fork of the Kern River. The rocks are similar to those of Table Mountain.

(5) Trout Creek. The gorge of Trout Creek, about 750 feet deep, separates into two areas what was formerly a continuous flow of gray to red, platy, banded basalt, with agglomerate at its base. These flows are the thickest in the region, about 300 feet.

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[7] Lawson, Andrew C., The geomorphogeny of the upper Kern basin: *Univ. Calif. Pub., Bull. Dept. Geol.*, **3**, 300–301; 320–322; 374–376 (1904).

[8] Knopf, Adolph, A geologic reconnaissance of the Inyo range and the eastern slope of the Sierra Nevada, California: *U. S. Geol. Surv. Prof. Paper* **110,** 73 (1918).

(6) The Niggerhead. On the northern edge of the Kernville quadrangle, basalt caps 75–100 feet thick form a large monolith-like mass. The lava cap is astride a contact zone between the two major batholithic units (granodiorite and quartz diorite) of the Southern Sierra Nevada.

(7) Main Canyon of the Kern. It has long been known that there are large andesitic and basaltic flows along the valley of the Kern River.[9] These are the most extensive in the entire southern Sierra. They occur in isolated outcrops northward along the Kern River for twenty-five miles, from a point about twenty-five miles north of Kernville. They are thought to have been extruded during the same period as those described above. Since they extend far to the north, in the areas described by Lawson[10] and Knopf,[11] they will not be included in this discussion.

Basalts

All of the rocks of the volcanic areas have petrographic similarities. The dense, black, platy aphanites do not contain many minerals recognizable megascopically. Sporadic globular or lenticular xenocrysts of gray, glassy quartz, up to one-quarter of an inch in diameter, occasional grains of olivine, and xenolithic masses of granitic (and pegmatitic) country rock, up to three feet across, are all that can be seen in the average basalt.

Microscopically, subhedral to euhedral olivine microphenocrysts, often altered to iddingsite, labradorite laths, and magnetite occur in a holocrystalline pilotaxitic ground mass. Some facies carry prismatic subhedral crystals of augite, or pigeonite, also as microphenocrysts. Basaltic hornblende occurs in some andesitic facies. Occasionally the plagioclase is medium andesine instead of labradorite. In places these form abundant euhedrons, which show strong strain shadows and zoning. Iddingsite, pseudomorphous after olivine, is a wide-spread mineral, particularly abundant in the red flows. It occurs in large pseudomorphs, with cores consisting of unaltered olivine grains. The iddingsite is deep brown, slightly pleochroic with strong dispersion, and shows the characteristic concentration of limonite and hematite around each iddingsite individual. Accessory minerals are abundant coarse grained magnetite, some of it secondary, and apatite in coarse rods and hair-like needles. In places the groundmass is hypocrystalline; locally pitchstones are encountered although glassy facies are rare.

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[9] Lawson, Andrew C., *op. cit.*, 300.

[10] Lawson, Andrew C., *op. cit.*, 320.

[11] Knopf, Adolph, *op. cit.*

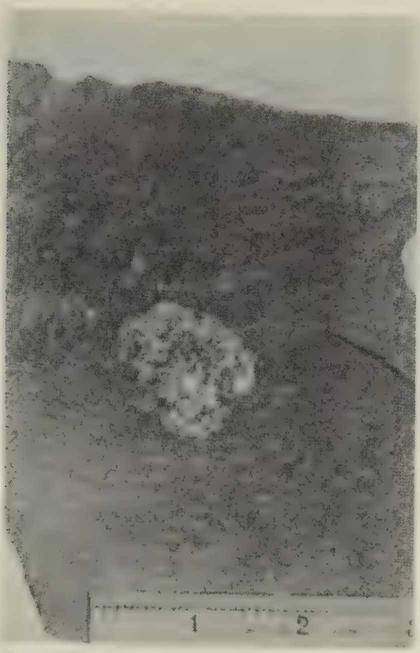

FIG. 2. Iron stained quartz-rich inclusion in basalt of the Bartolas group. Enclosure composed of a few grains of andesine with corroded margins, and many grains of strained quartz.

QUARTZ-BEARING BASALTS

Mode of Occurrence and Description of the Quartz

Quartz has been observed widely distributed in rocks of the Bartolas, Table Mountain, Black Mountain, Trout Creek, and Niggerhead areas. It occurs commonly as angular grains, and as angular and rounded granular aggregates. Usually it is much corroded at contacts with the basalt. Contacts of quartz grains with the basalt are always exceedingly sharp, although the quartz grains have been corroded and embayed. This seems anomalous in view of the reaction relations shown by some of the associated minerals[12] in the same environment; it has been suggested[13] that these sharp contacts are due to the fact that the quartz lacks a good cleavage. However, many of the contacts simulate the outlines of conchoidal to subconchoidal fracture, and it may be that the contacts repre-

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[12] See below.

[13] Larsen, E. S., and Switzer, George, An obsidian-like rock formed from the melting of a granodiorite: *Am. Jour. Sci.*, **237,** 563 (1939).

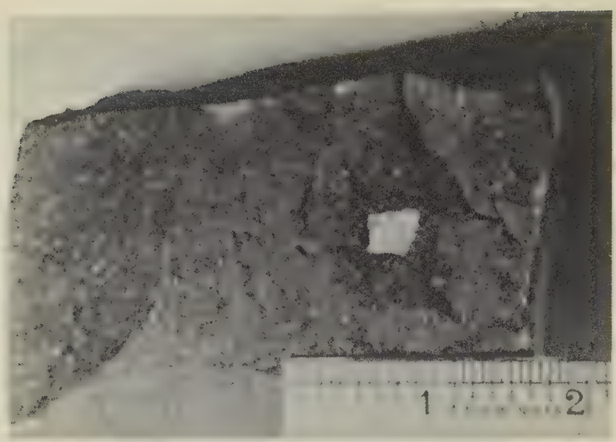

FIG. 3. Angular inclusion of quartz in olivine basalt of Big Table Mountain. Olivine grains are closely adjacent to this inclusion.

sent actual fracture surfaces, produced by temperature changes during the course of crystallization of the basalts. The crackling of quartz granules internally under similar conditions has been recognized.[14] In addition to the quartz granules, sporadic inclusions of pegmatite, composed of

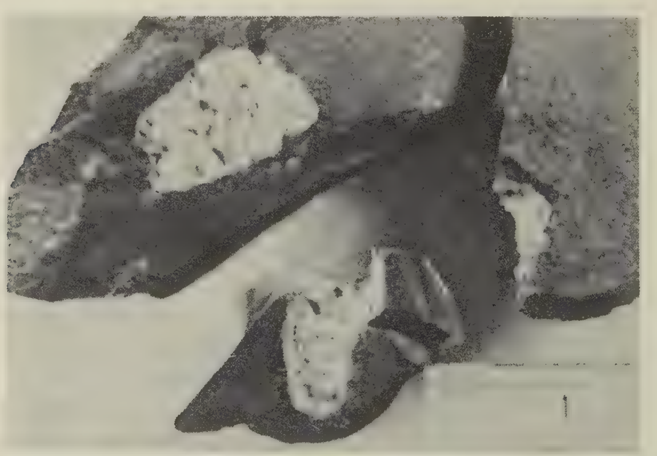

FIG. 4. Masses of quartz-rich pegmatite included in olivine basalt. Note the small percentage of feldspar. The fractured nature of the quartz may explain the source of many angular inclusions of pure quartz, since the original quartz might readily be broken up and mechanically incorporated as small angular grains similar to the one shown in Fig. 3.

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[14] Knopf, Adolph, Partial fusion of granodiorite by intrusive basalt, Owens Valley, California: *Am. Jour. Sci.*, 5th Ser., **36,** 376 (1938).

milk-white quartz (80–90%) and microcline are found. These inclusions are as large as 1½ inches in diameter, and are abundant locally.

GRANODIORITE XENOLITHS

Inclusions of granodiorite, derived from the formation upon which most of the lavas were extruded, occur in many of the flows of the southern Sierra Nevada. The inclusions often are extremely abundant, and all stages of alteration and digestion have been recognized. In texture and mineral composition the inclusions are on the whole the same as the Isabella granodiorite, from which it is thought they were derived. Little alteration can be noted by megascopic examination, although microscopic studies show significant changes in some xenolithic margins.

Size and Shape of the Inclusions. Recognizable granitic inclusions vary in size from one inch to two or three feet in diameter. Only one inclusion has been observed in three dimensions; in this the average was two feet on a side; the smallest size given represents those that can be positively identified as granodiorite. Inclusions of much smaller size are commonly composed chiefly of quartz, with a few grains of altered feldspar. These are remnants of larger inclusions which have been almost completely digested or which have been torn from larger masses along the route of flow. Irregularly shaped masses are typical, although spheroid, ovoid, and elongate ones have been found.

Distribution of the Inclusions in the Flows. Inclusions have been observed in all flows in the Kernville area. They have random distribution in the flows, ranging throughout the thicknesses exposed, although local concentrations near and at the contact of the flows with the crystalline basement are encountered. In a one hundred foot vertical thickness in Table Mountain, one finds inclusions in all parts of the outcrop. The same is true of the Niggerhead, although the vertical face is higher. In the Niggerhead, inclusions are quite abundant near the base of the flow; in the Trout Creek group, they are more common at the top; in Table Mountain only very large inclusions are seen.

ALTERATIONS OF THE XENOLITHS

Many of the xenoliths show evidences of alteration since their introduction into the basaltic magma. There are noted: (1) alteration rims about many inclusions varying from one to three centimeters in width, with gradations in grain size and texture from xenoliths to the basalt, (2) apparent leaching effects where feldspars have been largely removed, leaving granular and spongy-appearing quartz and residual feldspar, (3) visibly greater shattering of feldspars and fracturing of quartz in inclusions than in the normal granitic rock (this shattered condition has been noted by other workers in similar occurrences),[15] (4) almost complete removal of feldspar. Where this has occurred, quartz granules are considerably larger than the grains found in the normal granitic rock. Microscopic study shows different optical orientations in these grains, suggesting aggregations of smaller quartz units into quartz-rich areas, residual from altered xenoliths. Subhedral boundaries on quartz grains in pegmatitic inclusions, and their absence in these aggregations precludes their being pegmatitic xenoliths.

Microscopic examination of the transition zones between basalt and xenoliths show mineralogical and textural changes in the enclosed minerals. The alteration rims so prominent megascopically are seen microscopically to be composed of minerals which in part represent transitional products between basalt and granitic rocks, with intermediate recrystallization textures. Mineralogical relations within transition zones include (a) the inversion of orthoclase to sanidine, (b) the formation of clinopyroxene (probably diopside) in a zone transitional between olivine-rich basalt and granite but with no direct olivine-quartz contact, (c) etching and replacement of quartz by orthoclase, and (d) development of spinel.

A typical contact rim surrounding a xenolith is one to two centimeters in width. The rim is commonly in sharp contact with the enclosing rock and gradational with the granitic enclosure. This is interpreted as suggesting that the bulk of the material of the reaction rim is recrystallized xenolith and not material introduced by the magma. Resorption of the olivine and some iron ores contained in the basalt are the only apparent contributions of the basalt to the recrystallized zone. This interpretation is supported further by the absence of introduced glass in the reaction zone, glass being an important constituent of similar contact zones elsewhere.[16] The clinopyroxene, spinel, and iron ores of the contact zone occur in a groundmass of coarse grained potash feldspar, mostly sanidinized. The sanidine poikilitically includes all other minerals,[17] except quartz. Opening of the sanidine along its cleavage is prominent, although infiltration of other minerals has been slight. Some cleavage cracks have been filled with minute crystals of clinopyroxene and some iron ore.

Formation of clinopyroxene in a zone intermediate between olivine-rich and quartz-rich rocks has occurred in zones. The clinopyroxene oc-

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[15] Lacroix, A., Etude sur Le Metamorphisme de Contact des Roches Volcaniques: *Memoires, L'Academie des Sciences de L'Institut de France*, **31,** 19 (1894); Knopf, Adolf, *op. cit.*, 74–75 (1918).

[16] Richarz, Stephen, Some inclusions in basalt: *Jour. Geol.*, **32,** 686 (1924). Knopf, Adolph, *op. cit.*, 374 (1938).

[17] Similar relations are described by Williams, Howel, Pliocene volcanoes of the Navajo-Hopi country: *Bull. Geol. Soc. Am.*, **47,** 151 (1936).

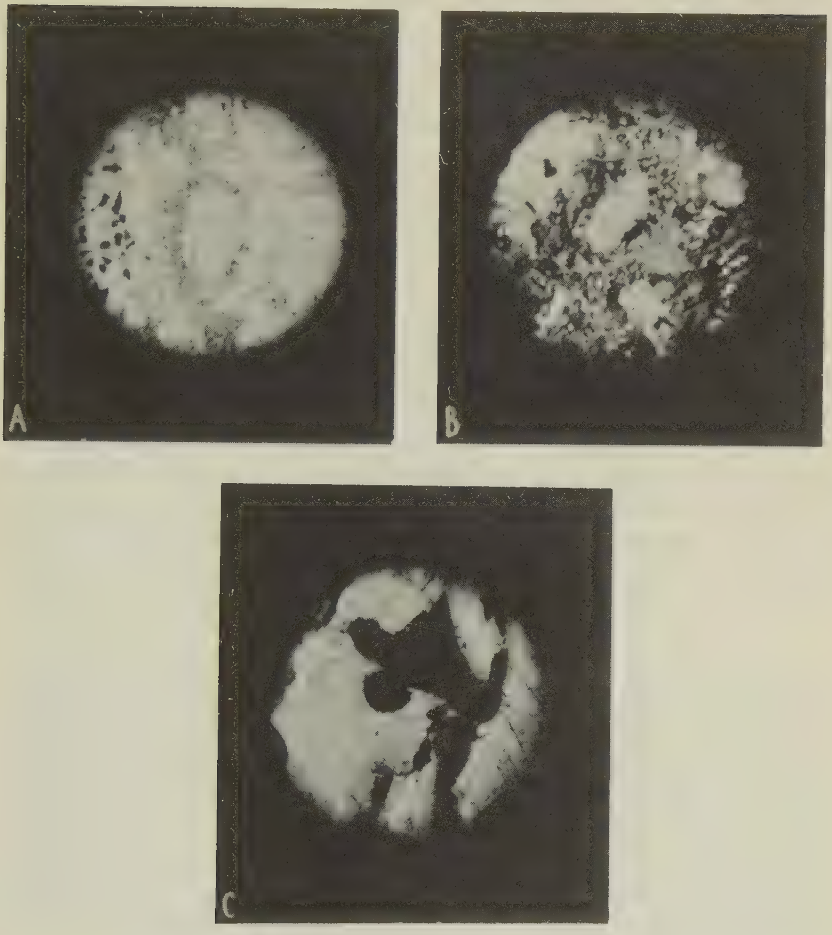

FIG. 5. Photomicrographs of three stages in alteration of a quartz monzonite inclusion in basalt.

A. Grain of quartz surrounded by clinopyroxene needles. Dark-colored grains are olivine stained with hematite in basalt. Note concentration of diopside grains toward basalt, and lesser concentration against quartz monzonite inclusion. ×16.5.

B. Quartz grain showing abundance of clinopyroxene in contact zone, and distribution of clinopyroxene throughout margin of inclusions; contrast between feldspar (lower right, showing Carlsbad twin) and quartz reaction well shown. × nicols. ×16.5.

C. Etched and corroded quartz grain which has reacted with adjacent perthitic orthoclase. Note the peculiar shape of the quartz anhedron. × nicols. ×16.5.

curs most prominently in halos about grains of quartz. Prisms commonly arrange themselves with their longest dimension normal to the contact surface of the surrounded mineral. The clinopyroxene in tinged greenish on its edges in certain grains, with some grains of a uniform green color over much of the surface of an individual. Always, however, the color grades off marginally into the normal colorless or nearly colorless clinopyroxene. In the contact zone where quartz grains of granitic inclusions lie at the adjacent contact or within the zone, the olivine has reacted directly to form clinopyroxene halos. Pyroxene grains are most abundant on the basalt side of the contact but they completely encircle the quartz. Where orthoclase lies in the contact zone, the clinopyroxene is less abundant. Where pyroxene is associated directly with orthoclase, textural relations suggest the source of silica to have been from the orthoclase. This may have been accomplished by (1) the extraction of the silica in a molecule of orthoclase and subsequent reunion of the alkalies and alumina with quartz to reform orthoclase, or (2) the loss of part of the silica in orthoclase, with a reaction stage in which leucite was present but in which concurrent reunion of leucite and quartz occurred to reform orthoclase.

The second hypothesis is extremely unlikely in view of the relations of the minerals actually present in the rock. The temperatures existent during the reaction period are suggested (1) by the presence of sanidine, (2) lack of intensive alteration of the xenoliths, and (3) the absence of tridymite inversion of quartz. Since sanidine has formed only in marginal rims, and not throughout the inclusions, a temperature not higher than 900° C.[18] is indicated, and the possibility is strong that the minimum temperature of 600° C. which must prevail if sanidine is to be stable was not much exceeded.[19] Some glass might be expected below 870°; at this temperature, also, quartz would invert to tridymite. Since neither of these changes are recorded, temperature relations are indicated which make it seem impossible for leucite to have formed even as a reaction stage during the development of the clinopyroxene from orthoclase.

The other hypothesis that silica was subtracted from orthoclase, and the residual alkalies driven toward the central portions of the granitic inclusions, receives support from peculiar textures developed inside of the sanidine rim and marginal to the less altered inclusion. In and adjacent to the marginal zone an anastomosing myrmekite-like texture is produced in the quartz anhedrons. Each irregular quartz grain extinguishes uni-

[18] Merwin, Herbert E., The temperature stability ranges, density, chemical composition and optical and crystallographic properties of the alkali feldspars: *Jour. Wash. Acad. Sci.*, **1,** 59 60 (1911).

[19] Winchell, A. N., Elements of Optical Mineralogy, Part II, Description of Minerals. Wiley and Sons, *New York*, 362 (**1933**).

formly and is physically and optically continuous. Small embayed quartz grains often extinguish with other quartz grains nearby, even when completely surrounded with perthitic orthoclase which has not been altered to sanidine. Inside the margins of xenoliths, there are normal contact relations between the quartz and orthoclase. This is cited as evidence that after reaction of orthoclase in the margin with olivine to form clinopyroxene, the residual alkalies migrated inward and combined with quartz to reform orthoclase. That this pseudo-myrmekitic texture was not produced by late-stage alkalies, introduced after the magmatic stage, is suggested by the absence of biotite in the suite, since the clinopyroxene of the reaction zone would normally be expected to proceed toward biotite and chlorite, if a late stage post-pyroxene alkali episode occurred. Occasionally small remnants of quartz lie irregularly along orthoclase cleavages, or astride them always with embayed margins. Although this textural relation has often been cited to show that quartz has replaced orthoclase[20] it has recently been suggested that too close adherence to this interpretation may lead to error.[21]

A few grains of a deep green euhedral isotropic mineral are identified as spinel. They are rare, and when found, occur in mats of clinopyroxene crystals.

Sources of Xenoliths

The presence of granodioritic xenoliths in various stages of alteration suggests that the granodiorite basement contributed siliceous material to the subsiliceous magma late in its magmatic history. It is believed that many of the inclusions were torn off fissure walls while the magma was rising through conduits in the granodioritic rocks. Fragments were detached and included in the magma, and were carried out with the extrusion. Concentrations near the base of some flows indicate that other xenoliths were picked up from exposed surfaces or that some settled out during cooling. Where basal concentrations of xenolithic material occur, it is common to find (1) radial tension cracks around inclusions, (2) no appreciable alteration of the xenoliths, and (3) rounded xenoliths, more deeply weathered than many of the abundant angular inclusions higher in the flows. The basal concentrations are therefore probably due chiefly to inclusions picked up from the weathered surface upon which the basalt was extruded.

It seems that xenoliths derived at depth would be more completely altered texturally and mineralogically than those derived from exposed surfaces at a time when congealment of the magma was imminent. The association of olivine and quartz in the same rock, often nearly side by side, and the general relations shown by the xenoliths to the enclosing rock establishes the fact that some silicic material was introduced in a late magmatic stage.

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[20] Schaller, Waldemar T., Mineral replacements in pegmatites: *Am. Mineral.*, **12,** 61 (1927); Bastin, E. S., and others, Criteria of age relations of minerals, etc., *Econ. Geol.*, **26,** 605 (1931).

[21] Wahlstrom, Ernest E., Graphic granite: *Am. Mineral.*, **24,** 698 (1939).

Radial Tension Cracks

Surrounding some of the inclusions, radiating outward from them, tension cracks often appear, generally in 5 or 6 directions. The larger cracks often extend distances as great as six feet into the basalt, radiating from inclusions as small as two inches on a side. Between the master radii lie shorter cracks, often less than an inch in length. These seem to be the result of tensional forces applied in the magma, just prior to consolidation

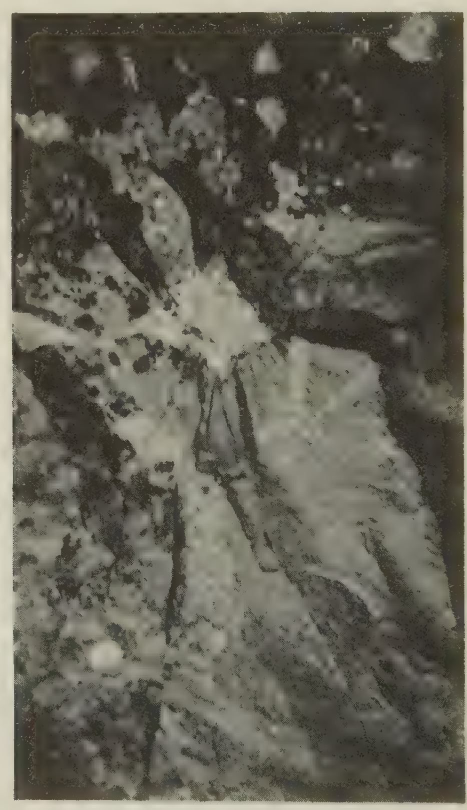

Fig. 6. Inclusions of granitic material in olivine basalt. Note tensional joint cracks radiating from inclusions. Small joints are developed subradial with the larger ones around the inclusions. Inclusion two inches on longest side. From the Niggerhead.

and continued during cooling to atmospheric conditions. The mechanism of their development is less obvious, however, particularly since the size of the master cracks are quantitatively disproportional to the size of the foreign inclusions about which they form; yet it is obvious that the tensional forces producing the cracks must have been set up following the introduction of the xenolith.

Of the many inclusions examined, tension cracks were found only about those xenoliths which showed little or no alteration of the included material. This immediately suggested later introduction of those xenoliths about which cracks developed, at a time when crystallization was nearly complete.

Analogous development of radial cracks seems to be found in certain reactions of glasses in the laboratory. When mounting metal tubes or rods in glass under atmospheric conditions, it is common knowledge[22] that glass, containing a platinum mount, even when prepared with extreme care, invariably upon cooling shows tension cracks in the glass radiating outward from the platinum. The size of these cracks is proportional to the coefficient of expansion of the glass, diameter of the metal rod, rate and uniformity of heating and of cooling, and other factors. The cracks develop in response to tensional forces set up in the glass tangential to the rod at all points. Only when the enclosure is coated with a cushion of liquid,[23] or some substance which can react with the glass, is the tensional force equalized (or minimized by the composition gradient) in all tangential directions. If the rod is dry, the forces are unequal tangentially, and cracks develop. Furthermore, if a square cross section of metal is introduced the forces are greatest at the corners, longer cracks develop radiating from the sharpest angles, and smaller cracks develop elsewhere, normal to the metal surface, and with random distribution. By analogy, then, xenolithic material, included in a basaltic magma, which crystallizes partially as glass, or of uniform fine grain, might be expected to act similarly. Since, in the case in question, the coarse grains of the inclusions would provide many irregularities for a maximum concentration of tangential force, and since little or no coating of low-viscosity would be expected on an inclusion that was introduced at a late stage, a maximum development of cracks might be expected, with some cracks more prom-

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[22] Houskeeper, William G., The art of sealing base metals through glass: *Jour. Am. Inst. Elect. Eng.*, **42**, 954 (1923).

[23] A French patent by G. Berlemont describes a method of sealing platinum wire, containing iridium, into quartz tubes by heating the quartz in the oxyhydrogen flame with one end of the tube in platinic chloride ($PtCl_4$) with a suction pump drawing the solution up the tube and around the wire between wire and glass during heating, to insure a tight seal around the joints. *Chemical Abstracts*, **8**, 411 (1918); and Houskeeper, William G., *op. cit.*, 957, for a similar process with base metals.

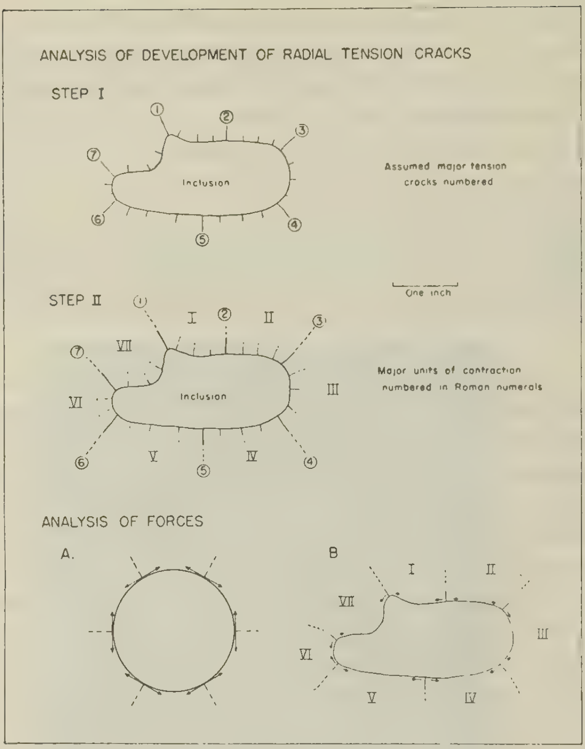
ANALYSIS OF DEVELOPMENT OF RADIAL TENSION CRACKS
STEP I
①
②
③
④
⑤
⑥
⑦
Inclusion
Assumed major tension cracks numbered
One inch
STEP II
I
II
III
IV
V
VI
VII
Inclusion
Major units of contraction numbered in Roman numerals
ANALYSIS OF FORCES
A.
B

Fig. 7. Assuming a cushion of liquid of low viscosity about a sphere of composition such that it would react with the liquid, tangential forces under the composition gradient produced would be insufficiently strong to develop tensional cracks in the cooling matrix. If cushion of liquid is absent, or the liquid is super cooled, *regularly spaced* and *equal length* cracks would be expected in the same time period. An inclusion of irregular shape would act similarly to the sphere, given a cushion of liquid; however, without the liquid cushion, cracks would develop whose length and spacing were determined by the irregularity of the inclusion, the longest cracks to be expected where the sharpest angles were found on the inclusion. Such major cracks, radial to the inclusion, would define major contraction units.

inent than others, but none quantitatively disproportionate to the other. Since complete congealment of a basalt might reasonably be expected at a minimum temperature of 500° C.,[24] considerable contraction of the basaltic rock is to be expected as atmospheric conditions are approached.[25]

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[24] Day and Shepherd reported surface temperatures at the top of the lava column of Kilauea of 1070° and 1185° C., respectively. [Water and volcanic activity: *Bull. Geol. Soc. Am.*, **24,** 601 (1913)]. Grout, [Petrology and Petrography, McGraw-Hill, 145 (**1932**)] states that lava at Kilauea flows slowly at 600° C.

[25] "Diabase contracts between 3.5–4% on solidification," Barus, Carl, High temperature work on igneous fusion and ebullition: *U. S. Geol. Surv., Bull.* **103**, 25 (1893).

Since cracks of maximum size develop about those xenoliths with maximum marginal irregularities it would be expected that during cooling toward air temperature, the lines of maximum cracking would continue to enlarge outward as on the spokes of a wheel with 5–6 directional radii most common. This might be likened to the extension of a crack in a plate or other glass as time elapses after a small crack forms. This is in essence considering a mass of infinite size, contracting about a nucleus of foreign material considered as a point.

By the development of the maximum tensional cracks, units of volume are defined which are bounded by these master radii, which continue in their development outward, and encompass larger and larger units of volume. Figure 7 expresses diagrammatically these relations.

The introduction of cold rock into a viscous mass near the temperature of congealment would also aid in the development of the radial cracks because of a slight chilling effect, setting up stresses similar to those formed during development of columnar joints, where the effective control is cooling from a plane or nearly plane surface downward.[26] If, however, a cooling surface is irregular, such as it would tend to be where xenoliths were adjacent, such stresses would be more irregular than in columnar jointing, accentuating further the development of tensional cracks, particularly at sharp and reentrant angles on the cooling (xenolithic) surface. The small size of the xenoliths, however, compared to the bulk of matrix would suggest that this was only a slight contributing factor.

Another contributing, though lesser factor, is the difference in coefficients of thermal expansion (and contraction) of the minerals of the xenoliths and the xenolith itself compared to the coefficient of the matrix.

It has been pointed out that such radial cracks have been observed around only a few zenoliths—those without reaction rims. About other xenoliths of granite, but of larger size, where cracks are absent, are found reaction rims forming a transition zone between matrix and enclosure. Referring again to laboratory techniques in glasswork, if some more chemically active metals are mounted in glass, such as copper or tungsten tubes or rods, it is possible to produce a mount without cracks around the rod when an intermediate mixture of glass and oxide of metal can be formed. Thus in tungsten rods, if they are thoroughly cleaned, then oxidized, and inserted in molten glass, the tungsten oxide diffuses through the glass marginal to the metal rod and forms a reaction rim or "corona" between the glass and tungsten equalizing thermal coefficients in metal and glass and preventing radial tension cracks.[27] Thus, Dr. J. B. Ramsey, of the Department of Chemistry, University of California, Los Angeles, having the above field facts described to him, predicted on the basis of the analogy with rod mounts in glass, that those inclusions without surrounding cracks would show reaction rims, and those with cracks little or no "corona." It seems, therefore, that those inclusions which show radial fractures must have entered the basalt late in its consolidation history, at a time when the magma was near enough to its consolidation temperature to preclude alteration.

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[26] Iddings, J. P., igneous Rocks. Vol. 1 (Wiley), 320 (1920).

[27] Houskeeper, William G., *op. cit.*, 957 (copper). McCullough, James D., Department of Chemistry, University of California, Los Angeles, personal communication.

ORIGIN OF THE QUARTZ

Hypotheses for the origin of quartz in basalts have been discussed in many papers. The present status of these hypotheses has been summarized by Finch and Anderson,[28] and by Daly.[29] Theories of direct crystallization from a primary magma,[30] differentiates of normal basalts,[31] deuteric alteration,[32] hybridism,[33] and contamination of basaltic magma,[34] have been advanced at various times to account for occurrences of quartz-bearing basalt. Study of the quartz grains found in the basalts of the southern Sierra Nevada suggests that mechanical contamination of a basaltic magma by granodiorite and granite xenoliths, with but limited reaction developing new minerals, produced the quartz xenocrysts.

In summation, evidence has been presented to show that, (1) various stages of alteration of granodiorite xenoliths are represented in the basic flow rocks, (2) small inclusions are now composed mainly of quartz, with few feldspar remnants, but with all gradations from pure quartz to pure granodiorite, and (3) olivine and quartz, closely adjacent, have not completely reacted. Since there is abundant proof of an originally uniform subsilicic composition of all the flow rocks, the conclusion seems inescapable that the free quartz described was derived from granodiorite and associated rocks in two ways: (1) as residues after alteration of very small granodiorite xenoliths, introduced late in the magmatic history, or from larger xenoliths introduced at an earlier stage, (2) as products of mechanical fragmentation of larger quartz-rich or pure quartz masses. The shattering of giant-textured quartz-feldspar aggregates during extrusion is suggested by the peculiar angularity of residual quartz grains, and also by the presence of broken, but unseparated, xenolithic masses of nearly pure milk-white quartz, often an inch or more in diameter.

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[28] Finch, R. H. and Anderson, C. A., The quartz-basalt eruption of Cinder Cone, Lassen Volcanic National Park, California: *Univ. Calif. Pub., Bull. Dept. Geol. Sci.*, **19,** 259–260 (1930).

[29] Daly, R. A., Igneous Rocks and the Depths of the Earth. McGraw-Hill, New York, 404–407 (1933).

[30] Diller, J. S., The latest volcanic eruption in northern California and its peculiar lava: *Am. Jour. Sci.*, 3rd Ser., **33,** 45–50 (1887). A late volcanic eruption in northern California and its peculiar lava: *U. S. Geol. Surv., Bull.* **79,** 21–33 (1891).

[31] Bowen, N. L., The evolution of the igneous rocks, Princeton University Press, 83–85 (1928).

[32] Fenner, C. N., The Katmai magmatic province: *Jour. Geol.*, **34,** 753 (1926).

[33] Harker, A., The Natural History of Igneous Rocks, Methuen & Co., 356 (1909).

[34] Daly, R. A., *op. cit.*, 407.

The angularity of the quartz grains, without crystal boundaries, together with the fact that granular masses are composed of many grains of different optical orientation, seems to the writer to warrant the conclusion that no process calling for direct or indirect crystallization from a magmatic body could account for the quartz.

ACKNOWLEDGMENTS

The field work on which this study was based was begun in 1932. During the progress of this and other work in the southern Sierra Nevada many individuals cooperated. Field assistance was given by several senior and graduate students of the University of California, Los Angeles. Doctors Cordell Durrell, James Gilluly, and W. J. Miller, of the Department of Geology, Doctors James D. McCullough and J. B. Ramsey, of the Department of Chemistry, of the University of California, Los Angeles, assisted by conference on and criticism of the manuscript. Dr. Ian Campbell, Division of the Geological Sciences, California Institute of Technology, and Dr. A. O. Woodford, Professor of Geology, Pomona College, kindly read the manuscript. Mr. Robert P. Bryson, now of the United States Geological Survey, cooperated in some of the field studies, and criticized the manuscript. These services are gratefully acknowledged. The writer, however, assumes full responsibility for all opinions herein expressed. Funds for the investigation were provided in part by the Research Committee of the University of California, Los Angeles.

THE UNIT CELL OF DICKINSONITE

C. W. Wolfe,
*Harvard University, Cambridge, Massachusetts**

The crystallography of dickinsonite has been described by G. J. Brush and E. S. Dana (1878) and (1890). The material examined by them was unsatisfactory for an accurate determination of the elements. In the course of my investigation of the minerals of the chemical type $A_3(XO_4)_2 \cdot nH_2O$, dickinsonite from Poland, Maine, was studied by x-ray diffraction methods to see whether it properly belonged in the type. The conclusion is that it does not, and for that reason the data obtained are given here.

The type Branchville material in the Harvard collection was not suitable for accurate work. A powder picture of the type material, however, proved to be identical with one of dickinsonite from Poland, Maine, which had been described by Berman and Gonyer (1930). Two crystals of the Poland material were studied morphologically, and x-ray diffraction pictures were obtained from one of them. Both lines of study gave concurrent results.

The zone [010] was well developed on the crystals, making orientation about the b-axis simple and accurate. Rotation, 0-layer-line, and 1-layer-line pictures were taken about this axis, and rotation and 0-layer-line pictures were taken about the [001] axis. The following constants were derived from these pictures.

$$\begin{aligned} a_0 &= 16.70 \text{ Å} \\ b_0 &= 9.95 \text{ Å} \quad a_0:b_0:c_0 = 1.695:1:2.507 \\ c_0 &= 24.69 \text{ Å} \\ \beta &= 104°41' \end{aligned}$$

The reflections observed on the Weissenberg pictures are:

hkl with $h+k$, even
$h0l$ with h, even and l, even
$h00$ with h, even
$0k0$ with k, even
$00l$ with l, even

The crystals are holohedral, and the space group is $C_{2h}^6 - C2/c$.

The elements given by Brush and Dana are:

$$a:b:c = 1.73205:1:1.19806;\ \beta = 118°30'.$$

The correlation between these elements and the elements determined in this study is only approximate, due to the poor character of the crystals measured by Brush and Dana. The basal and side pinacoids, and correspondingly, the a and b axes are identical in the two orientations. Their

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* Contribution from the Department of Mineralogy and Petrography, Harvard University, No. 241.

a(100) probably corresponds to my $(\bar{1}01)$, although there is a difference of five degrees between their measured angle to the basal pinacoid and that obtained from my elements. Their *s*$(\bar{2}21)$ is (110) in the structural lattice. The transformation formula from Brush and Dana to the orientation adopted here is:

$$\bar{1}00/010/102$$

The approximate nature of this transformation is shown by the following tabulation of calculated angles for equivalent faces in the two orientations.

Brush and Dana			Wolfe	
(110) to $(\bar{1}10)$,	113°24′	=	$(\bar{1}11)$ to $(\bar{1}\bar{1}1)$,	113°56′
(001) to $(\bar{2}21)$,	82 02	=	(001) to (110),	82 21½
(001) to $(\bar{1}11)$,	61 08	=	(001) to (111),	61 48
(001) to (100),	61 30	=	(001) to $(\bar{1}01)$,	66 23
$(\bar{1}00)$ to $(\bar{2}21)$,	68 22	=	(101) to (110),	66 00

To check the foregoing work, type Branchville specimens were obtained from the Yale Brush collection through the courtesy of Mr. George Switzer. The measurement of four crystals gave concurrent results with those obtained on the Poland material. One additional form, *p*{111}, which is $\{\bar{1}11\}$ of Brush and Dana, was observed in good position and is included in the angle table. The transformed form list of Brush and Dana has not been included in the angle table given below except where the forms have also been observed by me.

TABLE 1. DICKINSONITE-MEASURED AND CALCULATED ANGLES

Forms	Size	Quality	No.	Measured		Calculated	
				ϕ_2	ρ_2	ϕ_2	ρ_2
001	L	B	4	75°19′	90°00′	75°19′	90°00′
110	S	E	1	0 16	32 40	0 00	31 38
102	M	D	1	44 08	90 00	44 15½	90 00
302	S	D	1	21 50	90 00	21 22½	90 00
401	S	C	1	8 19	90 00	8 55	90 00
$\bar{1}02$	M	C	1	116 53	90 00	116 40	90 00
$\bar{3}04$	S	C	1	132 22	90 00	131 29	90 00
$\bar{1}01$	M	B	1	141 48	90 00	141 42	90 00
$\bar{2}01$	S	D	1	161 19	90 00	160 18½	90 00
111	S	C	3	— —	38 32	33 12	39 34½
$\bar{1}11$	S	C	1	138 51	33 29	141 42	33 02

b(010) was observed on three Branchville crystals.

The two Poland crystals measured in this study were not completely developed. Consequently, positive orthodomes were found on one crystal, while negative orthodomes appeared on the other. All of the faces could be easily and accurately indexed. The check between measured and calculated values is fairly good, as is shown in Table 1. The x-ray elements were used as a basis for calculation.

The face $(\bar{1}11)$ was small, but definite. The deviation of its measured and calculated ϕ_2 values is probably due to a distortion of the crystal, as it is practically impossible to obtain a crystal which has not been somewhat bent. No evidence of such distortion could be observed on the x-ray pictures, however. Figure 1 is a composite picture of the two Poland crystals.

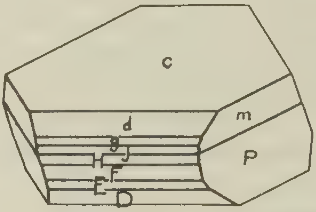

Fig. 1. Dickinsonite from Poland, Maine.

Table 2 gives the angle table for dickinsonite.

Table 2. Dickinsonite—Angle Table

Dickinsonite—$H_2Na_6Mn_{14}(PO_4)_{12} \cdot H_2O$

Monoclinic: Prismatic—$2/m$

$a:b:c=1.6784:1:2.4814$; $\beta=104°41'$; $p_0:q_0:r_0=1.4784:2.4004:1$

$r_2:p_2:q_2=0.4166:0.6159:1$; $\mu=75°19'$; $p_0'=1.5284$, $q_0'=2.4814$, $x_0'=0.2620$

Forms		ϕ	ρ	ϕ_2	ρ_2	C	A
c	001	90°00′	14°41′	75°19′	90°00′	—	75°19′
b	010	0 00	90 00	—	0 00	90°00′	90 00
m	110	31 28	90 00	0 00	31 38	82 21½	58 32
d	102	90 00	45 44½	44 15½	90 00	31 03½	44 15½
g	302	90 00	68 37½	21 22½	90 00	53 56½	21 22½
j	401	90 00	81 05	8 55	90 00	66 24	8 55
D	$\bar{1}02$	−90 00	26 40	116 40	90 00	41 21	116 40
E	$\bar{3}04$	−90 00	41 29	131 29	90 00	56 10	131 29
F	$\bar{1}01$	−90 00	51 42	141 42	90 00	66 23	141 42
H	$\bar{2}01$	−90 00	60 49	150 49	90 00	75 30	150 49
p	111	35 48½	71 54	33 12	39 34½	61 48	56 12½
P	$\bar{1}11$	−27 02½	70 15½	141 42	33 02	77 23	115 20

Chemistry. Three reliable analyses of dickinsonite have been made: two by H. L. Wells on material from Branchville, Connecticut, and one by F. A. Gonyer on a sample from Poland, Maine. The specific gravity values given for the Branchville dickinsonite are 3.143, 3.338, and 3.343. That given for dickinsonite from Poland is 3.266. All of the various impurities listed in the several analyses possess a specific gravity lower than that of dickinsonite. Their effect, therefore, would be to lower the determined value. On three separate mineral fragments of undoubted purity from Poland, I obtained a value of 3.38, 14.2 milligrams of selected material from Branchville gave 3.41, which is probably the best value. Using the value of 3.38 in conjunction with a cell volume of 3968.46 Å^3 obtained from the Weissenberg pictures, we obtain $4[H_2Na\ Mn_{14}(PO_4)_{12} \cdot H_2O]$ as the approximate contents of the unit cell. The calculated specific gravity is 3.42. Table 3 gives the derivation of this formula.

Table 3. Chemistry of Dickinsonite

	1	2	3	4	5	6
FeO	12.36%	13.61%		13.99	15.40	
MnO	31.91	32.44		36.58	37.19	
CaO	2.01	2.21		2.91	3.20	
MgO	1.67			3.37		
$\Sigma A''$	47.95	48.26	48.57%	56.85	55.79	56.00
Na_2O	7.42	7.66		19.46	20.10	
K_2O	1.73	1.56		2.99	2.70	
Li_2O	0.20	0.18		1.09	0.95	
$\Sigma A'$	9.35	9.40	8.26	23.54	23.75	24.00
P_2O_5	40.88	40.65	41.42	23.40	23.27	24.00
H_2O	1.82	1.69	1.75	8.22	7.65	8.00
Total	100.00	100.00	100.00			

1. Weight percentages—Poland dickinsonite—analyst Gonyer.
2. Weight percentages—Branchville dickinsonite—analyst Wells.
3. Weight percentages—theoretical formula $H_2Na\ Mn_{14}(PO_4)_{12} \cdot H_2O$.
4. No. of molecules in unit cell of "1." $M_0 = 8130.7$. Sp. Gr. = 3.38.
5. No. of molecules in unit cell of "2."
6. No. of molecules in unit cell of "3." $M_0 = 8230.6$. Sp. Gr. = 3.42.

The formula given for dickinsonite by Brush and Dana conforms to $A_3(PO_4)_2\cdot\frac{1}{3}H_2O$, which differs, principally, from the one given in this paper in that the H_2O is distributed between acid water and water of crystallization here, while the earlier authors make it entirely water of crystallization. The necessity for this change is indicated by the valence requirements which may be determined from columns "4" and "5."

References

Berman, H., and Gonyer, F. A. *Am. Mineral.*, **15**, 375 (1930).

Brush, G. J., and Dana, E. S., *Am. Jour. Sci.* **16**, 114 (1878); *Am. Jour. Sci.*, **39**, 213 (1890).

DJALMAITE, A NEW RADIO-ACTIVE MINERAL

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Introduction

While traveling through Conceição County, in the state of Minas Gerais, studying a pegmatite which is being mined for aquamarine and bismuth ore, Dr. Octavio Barbosa brought me a few specimens of minerals of the niobium-tantalate family, found on the Posse farm, in the Brejaúba district. The geological occurrence of the minerals has been described by him in *Mineração e Metalurgia*, vol. **11**, No. 13, 1938.

Three types of deposits are being worked at Brejaúba, and all of them come from the same pegmatite. They are: (1) the pegmatite itself; the mines being located at the top and on the hillside of Posse hill; (2) the eluvium which is derived from the erosion of the pegmatite; and (3) the alluvium of Posse creek (See Fig. 4).

The pegmatite is composed chiefly of kaolinized microcline and quartz found in veins and pockets; bismuth ore in "nests," associated with the quartz veins; non-commercial sheets of muscovite mica; green, yellowish-green, light blue and light brown beryl associated likewise with quartz veins; decomposed garnet; columbite; magnetite; monazite; samarskite; and tourmaline.

In addition to some of the above minerals, the alluvium contains a mineral similar to eschwegeite, emerald (rarely), and a new mineral with a yellowish-brown, greenish-brown or brownish-black color occurring in shining octahedral crystals, the description of which is given below. This mineral has sometimes been classified as betafite or microlite. A crystallographic study was made of the larger and more perfectly developed crystals.

Crystallographic Study

This new mineral is found in forms showing a perfect octahedron, modified on each corner by four faces, which with the octahedron gives a total of 32 faces (See Fig. 3).

In order to calculate the indices of these faces we used their relative position with reference to the octahedron faces. Thus, the angle between the face in question (*hkl*) and that of the octahedron (111) was found to be 28°23′.

The measurement was made with a Babinet goniometer. As the crystal did not have perfectly plane faces, small pieces of cover glass were glued to the faces, in order to obtain good reflections. However, in spite of this procedure a high degree of accuracy was not attained.

In like manner the angle of the adjacent octahedron faces was measured, the value of which was found to be 71°45′, the error being 1°14′. The inclination of the normal to the axes is 54°44′30″.

Figure 1 is a stereographic projection showing poles of both (111) and (*hkl*), indicated by P and P', respectively; X, Y, and Z being the projections of the rectangular axes.

In the triangle $P'PX$ the sides $P'P$ and PX and their included angle are:

$$
\begin{aligned}
PX &= 54°44'30'' \\
PP' &= 28°23' \qquad \text{(measured)} \\
\text{angle} \quad P &= 120° \\
\cos P'X &= \cos PX \cdot \cos P'P + \sin PX \cdot \sin P'P \cdot \cos 120° \\
&= 0.3138 \\
P'X &= 71°42'50''.
\end{aligned}
$$

The pole P' makes equal angles (71°42′50″) with X and Y, and an angle of 26°21′30″ with Z. The cosines of these angles are in the ratio of 0.3:0.3:0.9, hence the form has the indices (113).

The theoretical value of the angle $P'P$ between (111) and (113) can be calculated from Fig. 2.

$$
\begin{aligned}
\text{angle} \quad POZ &= 54°44'30'' \\
P'OZ' &= OAZ' \\
\tan OAZ' &= \frac{OZ'}{OA} = \frac{1/3}{1/\sqrt{2}} = 0.4106 \\
\text{angle} \quad OAZ' &= 25°14'20'' \\
\text{angle} \quad POP' &= 29°30'10''
\end{aligned}
$$

Thus the goniometric measurement was in error by 1°7′.

REFRACTIVE INDEX

The index of refraction has been determined by the immersion method. The immersion medium used was Merwin's solution, and the refractive index was found to be 1.97.

CHEMICAL COMPOSITION

The chemical composition is as follows:

Ta_2O_5	72.27
Nb_2O_5	1.41
TiO_2	2.54
SnO_2	Trace
ZrO_2	0.80
UO_2	2.17
UO_3	9.38
WO_3	0.18
Bi_2O_3	0.98
PbO	1.10
FeO	0.56
CaO	3.40
MgO	0.24
H_2O	4.62
	99.65

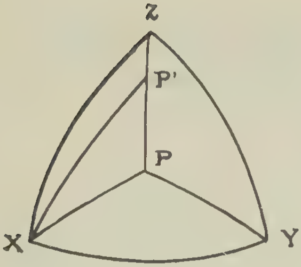

FIG. 1

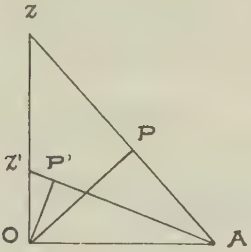

FIG. 2

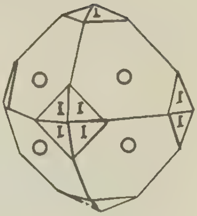

FIG. 3

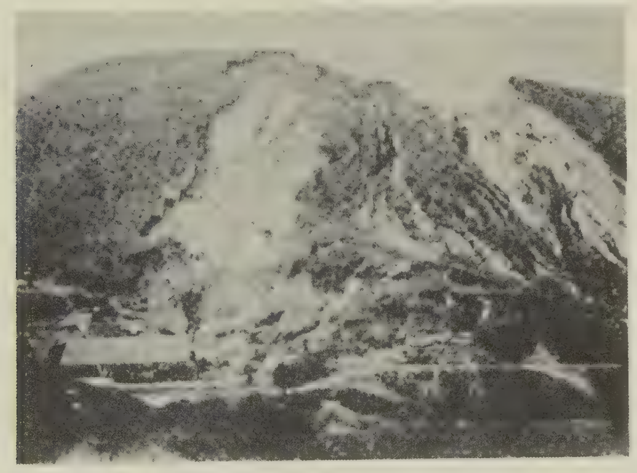

FIG. 4

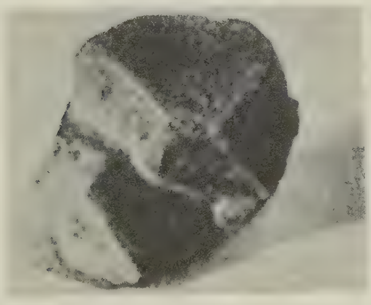

FIG. 5

Although it has not been possible to give an exact formula, on account of the alteration to a hydrate, the mineral is to be regarded as an uranium-bearing tantalate together with other bases and titanium in small amounts.*

PHYSICAL PROPERTIES

Color—04ie and 08ie of Ostwald scale.

Streak—04ge (light yellow) Ostwald scale.

Powder—04ge Ostwald scale.

Specific gravity—5.75–5.88.

Hardness—5.5.

Fracture—Irregular.

Cleavage—None.

System of symmetry—Isometric.

Habit—Octahedral.

Observed forms: icositetrahedron $i=(311)$ and octahedron $o=(111)$, the latter being dominant (Fig. 3).

OPTICAL PROPERTIES

In thin section the new mineral has the following properties:

Translucent, yellowish-brown, greasy luster, strongly refringent.

CHEMICAL COMPOSITION

A tantalate of uranium and other bases, with a small amount of titanium.

CONCLUSIONS

The physical properties of the mineral indicate that it is closely related to betafite and samirésite; it also resembles eschwegeite.

In the current literature no reference has been found for this mineral. As suggested by Dr. Octavio Barbosa, who furnished the specimens for the present study, we propose for the new mineral the name *Djalmaite.* It is a deserving tribute to Dr. Djalma Guimarães, the well known Brazilian mineralogist and petrologist.

ACKNOWLEDGMENTS

Thanks are due to both Drs. Octavio Barbosa and Viktor Leinz for their valuable suggestions, and to Dr. Emilio A. Teixeira for the translation of this note into English.

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* Note by Dr. Harry Berman.

The best formula obtainable seems to be of the type $AB_3O_8(O, OH)$ with $A=U^4, U^6$, Ca, Pb, Mg; and $B=(Ta, Cb, Ti, Zr)$.

The analysis represents a composition distinct from any recorded mineral and is apparently a Ta, U-rich member of the betafite group. Other members are blomstrandine, the titanium-rich member, and samirésite, with much lead.

NOTES AND NEWS

CLOSER INSPECTION OF INDUSTRIAL DIAMONDS PRIOR TO USE ADVOCATED

A. E. Alexander,
Bureau of Natural Pearl Information, New York, N. Y.

The article by Drs. Kraus and Slawson, on the "Cutting of diamonds for industrial purposes"[1] is extremely timely and should prove invaluable to the individual or firm engaged in the cutting and merchandising of this widely used industrial tool.

During the past ten years, the writer has at one time or other been associated with one or more firms manufacturing spark-plug porcelain. The conventional method, usually employed to process an extruded, unfired ceramic blank, is to shape the material on a silicon carbide or aluminum oxide wheel. Or, if the ceramic materials have been dry pressed, a final, finished shape can be imparted by the use of the same type of grinding wheel. These wheels are grooved to the desired form and the accurate dimensions and tolerances maintained by means of a specially cut diamond-set shaping tool.

In connection with this work, it was found after several months experience, that some of the industrial diamonds lasted very much longer than others. The life of the diamond, or its rate of wear was found to vary from a week to as long as a month-after which a new diamond had to be purchased, or the old one re-cut. At the writer's suggestion, a routine inspection of all industrial diamonds, prior to purchase, was installed. The method instituted consisted of two optical examinations, one using a polarizing microscope, the other employing conventional binocular equipment. It was found that many diamonds, when examined under crossed nicols, revealed that the stones were in a state of strain. The sales engineering representatives of the several firms which supplied the industrial diamonds in question, were interrogated about this phenomenon. Apparently no knowledge was had to the effect that the diamonds were so strained, nor was any microscopic examination of any kind (outside of possibly a jeweler's loupe) seemingly made on the stones held in stock.

In addition to the evidence of strain, it was further found that some of the industrial stones were flawed, or contained one or more types of inclusions. Again, many stones were cut as "conveniently" as possible, so that the face that could withstand the greatest wear, viz., the hardest, was not always correctly placed with respect to the particular shape wanted.

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[1] Kraus, E. H., and Slawson, C. B., Cutting of diamonds for industrial purposes: *Am. Mineral.*, **26**, 153–160 (1941).

As stated above, the stones were subsequently examined in lots, by means of appropriate optical equipment. Only those diamonds which were nearly free from strain or showed no evidence of this condition were chosen. Industrial diamonds, which were flawed or which contained inclusions of any kind which were so oriented in the stones as to cause possible failure on use, were eliminated from consideration. And lastly, any stone not properly cut was likewise unacceptable.

Where a large number of stones are used, the employment of an inspection system, along the lines suggested above, and performed preferably by an individual possessing some knowledge of the mineralogy and crystallography of the diamond, will do much to reduce replacement costs and unsatisfactory performance.

PROCEEDINGS OF SOCIETIES

THE PHILADELPHIA MINERALOGICAL SOCIETY

Academy of Natural Sciences of Philadelphia, December 5, 1940

Dr. Thomas presided, with 52 members and visitors present. Dr. Daniel L. O'Connell of the College of the City of New York addressed the Society on "The Saurel Symbols for the 32 Crystal Classes." By the use of only a center of symmetry, axes of symmetry, and inversion axes (planes of symmetry were ignored) a thoroughly consistent and logical scheme for deriving and designating the 32 crystal classes was developed by the late P. Saurel, Professor of mathematics in the College of the City of New York. The exposition of the system by Dr. O'Connell was discussed by Drs. Wherry and Patterson.

January 2, 1941

Dr. Thomas presided with 47 members and visitors present. Dr. George T. Faust of the U. S. Department of Agriculture spoke on "Economic Petrography," emphasizing the importance of petrographic analysis in planning methods for beneficiation of ores. Mr. Louis Moyd related some experiences on his mineralogical expedition into Ontario in November.

February 6, 1941

Dr. Thomas presided, with an attendance of 71 members and visitors. Dr. William Parrish of State College addressed the society on "Isomorphism and solid solution," in which data on atomic and ionic radii and their relation to coördination numbers were reviewed. Interstitial and substitutional solid solutions and the formation of stable compounds were discussed from the viewpoint of crystal chemistry and structure. They can be differentiated by specific gravity methods and *x*-ray studies. Factors influencing the formation of solid solutions such as the 15% rule (limit of tolerance of radii of replaceable atoms), close similarity in crystal structures, etc., were discussed. Ordered, disordered structures and superstructures were described. Some of the principles developed were illustrated in deriving chemical formulae from chemical analyses of sphalerites and spinel. The speaker stressed the importance of the study of compositional variation in mineralogy.

Mr. Louis Moyd exhibited peristerite and ellsworthite from Hybla, Ontario; cyrtolite, cancrinite, sodalite, biotite, hackmanite and nepheline from Bancroft; cyrtolite and tremolite from Otter Lake; calcite, fluorite, diopside, molybdenite, and fluorite from Wilberforce; and wernerite from Calumet, Ontario.

FORREST L. LENKER, *Secretary*

NEW MINERAL NAMES

Donbassite

E. K. Lazarenko: Donbassites, a new group of minerals from the Donetz basin. *Compt. Rendus* (Doklady) *Acad. Sci., U.R.S.S.*, **28,** 509–521 (1940).

Name: For the locality.

Chemical Properties: Four analyses are given (1) by Samoilov (1906), called α-chloritite by him, (2) by Sturm, from Zhuravaka, (3) by Lazarenko, from Utrennyaia shaft, (4) by Serdyuchenko, from Uralskaya vein.

	1	*2*	*3*	*4*
SiO_2	35.12	34.65	33.64	34.73
Al_2O_3	48.16	46.03	45.02	48.08
Fe_2O_3	—	0.55	1.38	1.04
MgO	tr.	1.58	1.75	0.80
CaO	0.61	1.82	2.03	—
Na_2O	1.98	1.08	1.30	—
Li_2O	—	0.14	tr.	tr.
H_2O	14.01*	13.96	15.20	14.58
	99.88	99.81	100.32	99.23

* Given as 4.01.

These analyses give the formulas: for (1) and (2) $H_{14}Al_8Si_5O_{29}$ or $4(H_2Al_2SiO_6)\cdot SiO_2\cdot 3H_2O$; for (3) $H_{18}RAl_{10}Si_6O_{37}$ or $5(H_2Al_2SiO_6)\cdot RSiO_3\cdot 4H_2O$; for (4) $H_{16}RAl_{10}Si_6O_{36}$ or $5(H_2Al_2SiO_6)\cdot RSiO_3\cdot 3H_2O$, where $R = Mg$, Fe'', Ca, Na_2, Li_2. The general formula is given as $P(H_2Al_2SiO_6)\cdot gA$, where $P = 1, 2, 3, 4, 5$; $g = 1, 2, \ldots$; $A = nH_2O$; $SiO_2\cdot nH_2O$; $RSiO_3\cdot nH_2O$. Before the blowpipe, infusible; whitens and splits into separate foliae. Gives water in a closed tube. Loss in weight up to $450° = 0.02\%$. Very slightly attacked by HCl and H_2SO_4; not attacked by HNO_3.

Physical and Optical Properties: White, flaky aggregates with pearly luster. Cleavage perfect, laminae flexible. $H. = 2\frac{1}{2}$. $G. = 2.63$. Optically biaxial, positive. $\alpha = 1.728$, $\beta = 1.729$, $\gamma = 1.735$, 2V 52°; dispersion marked, $r > v$. $Z{:}c = 0°$.

Occurrence: Found at a number of places in the ore veins of the Donetz basin in lode walls and in zones of crushing of rocks; also found as coatings on slickensides of coals.

Discussion: The refractive indices are remarkably high for a mineral having this composition, low specific gravity, and low hardness. The mineral obviously needs further study.

Michael Fleischer

Abkhazite

N. E. Efremov: The new mineral abkhazite. Trudy Instituta Geologicheskix Nauk (*Proc. Inst. Geol. Sci.*), *Acad. Sci. U.S.S.R.*, No. **11.** Mineral.-Geochem. Ser. (No. 3), 37–44 (1938) (in Russian).

Name: Named from the region, Abkhazia (North Caucasus, U.S.S.R.).

Chemical Properties: A variety of amphibole asbestos. Analysis gave: SiO_2 50.18, Al_2O_3 4.70, Fe_2O_3 8.30, FeO 1.20, CaO 16.14, MgO 14.58, MnO 0.67, K_2O (includes trace of Li_2O) 0.87, Na_2O 0.53, P_2O_5 0.76, H_2O+ 1.99, H_2O- 0.77, CO_2 none; sum 100.69. Formula given as $(OH)_2(Ca, Na, Mn, K)_3(Mg, Fe^{++}, Fe^{+++}, Al)_{4.5}(Si)_8O_{22.5}$.

Physical Properties: Color, grey, with greenish tinge. Occurs as groups of parallel fibers, resembling typical amphibole asbestos. G. = 2.30. Fibers easily separated. Under the microscope, grey with weak yellowish tint.

Optical Properties: Oblique extinction, $c{:}n_g = 16°$. Twinned; plane of optic axis $\|(010)$. $2V = 60°$. Sign (−). Optical character of flat zone positive. $n_g = 1.641$, $n_p = 1.624$, $n_g - n_p = 0.017$. Interference colors in thin section of normal thickness yellowish-grey, first order. Pleochroism strong.

X-ray Characteristics: As reported, seem to be essentially those of actinolite and anthophyllite.

Occurrence: In amphibole-asbestos deposits on the Adangia range, between the Bzibya and Chkhaltoi rivers, Abkhazia territory, North Caucasus, U.S.S.R.

Discussion: Placed by E. among the monoclinic amphiboles, and given species rank as having (Mg, Fe):Ca = 4:3, thus differing from others of this class.

J. P. Marble

The ninth summer program on spectroscopy and its applications will be held at the Massachusetts Institute of Technology beginning June 1 and extending until August 1. Requests for information regarding the spectroscopy conference and its program, and on the summer courses should be addressed to Professor G. R. Harrison of the Department of physics.

Dr. Charles H. Behre for the past eleven years professor of economic geology and chairman of the department at Northwestern University from 1933 to 1937, has been appointed professor of economic geology at Columbia University.